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SCIENCE APPLICATIONS, INC.

# AN ASSESSMENT OF POTENTIAL ROBOTIC APPLICATIONS TO NAVAL AVIATION OPERATIONS AND SUPPORT

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ASTR

( ADVANCED SUPPORT TECHNOLOGIES/ROBOTICS )

N00019-81-G-3102

**FINAL REPORT**

SEPTEMBER 1982

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Meridian Corporation

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OPERATIONS AND SUPPORT

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Sponsored by

NAVAL AIR SYSTEMS COMMAND, ASSISTANT
COMMANDER FOR RESEARCH AND TECHNOLOGY

(AIR-03)

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## EXECUTIVE SUMMARY


As a result of the obvious increases in industrial productivity attributable to robotic technology, the Department of Defense (DOD) has recently encouraged the individual services to initiate programs exploiting the potential military applicability of robotics. In response to this interest, the Naval Air Systems Command (NAVAIR) Assistant Commander for Research and Technology (AIR-03) contracted with Science Applications Incorporated (SAI) and Meridian Corporation (MC) to conduct an assessment of the potential applications of robotics to naval aviation operations and support. Specifically, the contract tasks were to:

- assess the state-of-the-art of current industrial robotic systems and technologies
- assess the potential application of these systems to naval aviction operations and support
- assess the requirement for a dedicated robotic technology base development within AIR-03
- develop conceptual robotic applications (if feasible) to naval aviation operations and support

It was assumed that in general, robotics could enhance overall operational effectiveness by increasing safety, reducing response time and, of course, increasing manpower effectiveness and/or reducing manning levels.

After a comprehensive review of industrial robotics, a comparison of Navy and industry unique requirements and a definitive assessment of potential naval aviation applications, it was concluded that;

1. Few, if any present industrial robotic systems are directly applicable to naval aviation needs, particularly in the at-sea environment;
2. Significant adverse reaction to and misunderstanding of, the term "robot" exist within the fleet and "blue collar" civil service;
3. Evaluation of robotic applications results in the recognition of a basic robotic concept - the elimination and/or enhancement of the "human transfer function" or presence in applications that are manpower-intensive, dangerous or inhospitable to the human presence, or otherwise basically

inefficient due to human limitations;

4. There is high potential for the robotic concept (above) to improve naval aviation manpower application and efficiency as well as overall operational effectiveness;

5. The robotic concept has been and is being well applied within the NARF's as a result of both internal and NAVAIR initiatives;

6. Combat/operational "robotic" efforts and concepts are numerous but not open for inclusion in a generalized "robotics program";

7. Due to definitive differences in "robotic" systems as applied to naval aviation operations and support and classical industrial robots, a need exists for the development and maintenance of a robotic (as advanced support technologies) "technology base" for the ultimate design of Navy-applicable systems for the elimination and/or enhancement of the human transfer function.

8. The initial robotics studies indicate that a technology base development program should logically be established in NAVAIR (AIR-03), and that this program should encompass both procedures for systematically developing a long-term ASTR technology base as well as systematic response to short-term fleet needs by exploiting state-of-the-art and emergent technologies via concept/technology demonstrator process.

It is recommended that, in light of these conclusions, NAVAIR implement an Advanced Support Technologies/Robotics (ASTR) Program within AIR-03.

AN ASSESSMENT OF POTENTIAL ROBOTIC APPLICATIONS TO NAVAL AVIATION OPERATIONS AND SUPPORT

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## Chapter I

### Introduction

Over the past several years, robots[1] and robotic technology have been given considerable public exposure, initially related to Japanese "superiority" in the auto industry, and more recently as fashionable high-technology. As a result of this exposure, robotic technology has come to be associated with dramatic increases in efficiency and productivity, causing senior management in both industry and government to initiate implementation programs.

The Department of Defense (DoD) has begun to explore the transferability of this technology to operational service applications as well as the more readily adapted in-house support and industrial uses.

Several state-of-the-art industrial robotic systems have been assessed for direct transfer to the military environment. These initial efforts have focused primarily on the in-house industrial applications, with some attention to logistics support of combat operations, such as cargo handling and warehousing.

In initiating the subject effort of this report Naval Air Systems Command's (NAVAIR) Assistant Commander for Research and Technology (AIR-03) recognized two key elements which must influence his perspective of military (naval) robotics applications, namely:

- naval aviation operations and their support elements are highly flexible and mobile, and
- naval operations and operational support are conducted in a non-permissive environment even in peace-time.

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[1]The Robotics Institute of America (RIA) defines a robot as being a "reprogrammable multifunctional manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks."

In full recognition of the uniqueness of the naval aviation mission and environment, the relative applicability and transferability of current and future robotic technology was investigated by:

- assessing the state-of-the-art of current robotic systems and technologies to provide AIR-03 with both a broad overview and detailed data from which to develop a working familiarity with this "new" discipline;
- assessing the potential for robotic applications to naval aviation operations and support, based on the insights gained from the previous technology assessment;
- assessing the requirement for a dedicated robotic technology base development within AIR-03, based on the results of the technology and applications assessments; and
- developing conceptual robotic applications to naval aviation operations and support.

The underlying assumption in this effort was that the systematic applicatio of robotic technologies to naval aviation operations and support could ultimatel

- increase total combat system effectiveness by selectively eliminating the "human transfer function" with its inherent time delay and error prone sensors;
- increase combat effectiveness by reducing operational support activities constrained by physical limitations;
- increase at-sea combat effectiveness by developing offensive and defensive capabilities currently unexplored due to physical incompatability with human functions and physical limitations;
- increase cost-effectiveness by ultimately eliminating significant number of personnel and the associated high "acquisition cost" and "life cycle (support) cost";
- decrease "turn around" time for weapons systems in repair/remanufacture; and
- increase safety by eliminating human presence in inhospitable environments and reducing "human error" as a causal factor in mishaps.

Naval aviation is particularly sensitive to human inadequacies due to the technical complexity of its hardware and operations, the hazards inherent in its environment, the "encapsulated" nature of at-sea maintenance and support, and the potentially catastrophic results of human error in this environment. There should be high potential pay-off for any system that can minimize these adverse influences.

Chapter II

Industrial Robotics

A. Background

The assessment of the state-of-the-art in robotic technology required in the reviewing of an extensive body of available information, far too voluminous to be discussed in detail in this report. As is the case with all "fashionable technologies" large amounts of highly generalized, subjective, ambivalent and just plain worthless information were discarded. That information that was judged to be of value in the formation of an in-house NAVAIR body of robotics knowledge was retained. The resulting data package continues to be extensive, but manageable, and has been organized into three elements, included as appendices to this report, and briefly characterized below:

1. Appendix I - Baseline Data

This Data Base element is composed of five comprehensive reports, considered to provide a definitive foundation of knowledge of robots, robotic technology, industrial applications, advanced automation, machine (artificial) intelligence, social impacts and potential integration of robotic and automation systems. A brief description of each of the five volumes follows:

a. ICAM Robotics Applications Guide

Provides a comprehensive introduction to robotics technology as applied primarily to the aerospace industry. The basic characteristics of robotic systems are defined, including capabilities and mode of operation. Sensor applications, robot tooling, work station integration and potential applications are also addressed in some detail. This volume also contains an excellent glossary of robotics terminology. The Robotics Applications Guide is perhaps the single most useful document in the Data Base associated with this report.

b. Industrial Robotics in the 1980's

Provides a detailed insight into the historical progression of industrial robotics applications, as well as a statistical review of industrial robotics. This report is somewhat unique in providing profiles of the principal robot builders and suppliers, with descriptions of their product lines. This volume also provides a valuable appreciation for general industrial attitudes and philosophy concerning robotics.

c. Machine Intelligence and Robotics

This report is a product of a Special NASA Study Group composed of academic leaders in the field of robotics, computer technology and artificial intelligence, chaired by "television personality", author, and university professor (Cornell) Dr. Carl Sagan. This report was found to be the most enlightening source available for understanding the somewhat ill-defined world of machine-intelligence and its interaction in robotics technology and applications.

d. Social Impact of Robotics

This is a summary of the proceedings of a workshop on the title subject sponsored by the Congressional Office of Technology Assessment (OTA). The report and its appendices objectively discuss the projected growth and impact of robotics on society in general, and U.S. and world economy in particular. The message to be gathered from this report, in particular from its lengthy appendices, is that statistically and politically heavy military involvement with robotics is inevitable.

e. "Factory of the Future"

This volume is a compendium of the presentations given at the subject title conference sponsored by the American Institute of Aeronautics and Astronautics (AIAA) in April and May of 1982. While this volume is by definition disjointed and short of data, it is the most timely broad insight into the world of robotics and allied technologies available. Due to the nature of the sponsor, the subject matter is heavily slanted toward the aerospace industry. This report clearly illustrates several important points:

- there is wide diversity of opinion on robotic applications and systems integration;
- significant problems exist in the efforts to integrate artificial intelligence and robotic systems in integral, multifunctional processes (i.e., "factories"); and
- there are no universally applicable robotic technologies - new applications require new subsystems, and new investment.

This volume should give NAVAIR managers considerable insight into the status of most current aerospace robotics development efforts. Particular attention should be paid to the conclusions and summaries of each presentation, especially the "problems remaining" sections.

2. Appendix II - Extension Data

This appendix, grouped in two consecutive volumes, is an organized collection of articles and reports on specific aspects of robotics and related technologies collected during the term of this contract. This segment of the Data Base is designed to readily provide the NAVAIR user with information on specific characteristics or aspects of robotics without having to digest the entire Baseline Data portion of the Data Base. It should be noted, however, that the Baseline Data is necessary for a working understanding of the myriad details involved with robotics, and that the Extension Data will update and expand that initial base. The Extension Data is designed to be maintained and expanded by the client in order to stay abreast of this rapidly expanding body of knowledge. The Extension Data presently includes coverage of:

- general robotic applications;
- special robotic applications;
- types of motion;

- sensory perception;
- power systems;
- computational systems;
- artificial intelligence;
- economics;
- productivity analysis; and
- social impacts.

3. Appendix III - Abstracted Data

The abstracts listed in this volume will provide NAVAIR with insight into the extent of discussion and research ongoing in robotics technology over the past two decades. Special interest in various aspects of these technologies may be pursued by ordering the related studies. The depth and diversity of the subject areas treated should be noted. The very recently published "Worldwide Robotics Survey and Directory", included in this portion of the Data Base seems very meager in content when compared to the vast body of information either included or represented in the Data Base. This directory is, however, indicative of the lack of a central authority, or order, governing or monitoring the growth of robotics and allied technologies.

Since the Baseline and Extension Data packages are totally part of the desired assessment, no attempt will be made to present any condensation of the information in this report. However, a simplified and generalized review of industrial robotics will be presented to facilitate the reading of, and preserve the continuity of, this report (primarily for those readers who prefer to address the Data Base at their leisure).

B. Review of Industrial Robotics

American industrial productivity increased at an annual rate of 3.4% from 1947 to 1965. From 1966 to 1976, productivity increased at an annual rate of

2.3%. During the 1977 to 1979 time frame productivity increased at 1% per year, and in 1980 this figure declined to an annual rate of only .9%. This progressive decline in American industrial productivity has increased unit cost, lowered the quality of goods and services produced, aggravated inflation, increased overseas competition and lower corporate profits. Faced with a deteriorating competitive edge and shrinking share of the domestic and international market, American industry assessed the situation, identified problem areas and initiated solutions.

An assessment of the deteriorating situation indicated that American products were of poor quality (material and workmanship) and were overpriced. As a result of the high wages and benefits paid by American industry to union labor, quality and material standards were lowered in an effort to reduce cost. A lack of proper motivation from American workers contributed to lower product quality and workmanship standards. Material cost saving measures assisted in holding down unit cost, however, coupled with the poor quality workmanship, American industrial products still lost respected quality status and are now losing their share of the markets.

Industrial economic planners, product quality control specialists and innovative engineers determined that the supplementation, or gradual replacement of labor with cost-effective quality controlled automation would again render American products competitive on the world market. Thus, robotic systems came to the forefront of American technology. This technology is now being transferred to practical application in industry. Labor cost can be reduced from $14.00 per hour (for a typical blue collar worker) to $4.80 per hour (for a typical robot). Efficiency can be increased from 75% (typical blue collar worker) to 98% with robotic systems capable of working 3 shifts, 7 days a week, 52 weeks out of the year. This type of efficiency and cost-effectiveness has led to the introduction of hundreds of robotic units into manufacturing. It is estimated that in 1982, 5% of all assembly systems used robotic technology and that by 1988, 50% of all human labor in the small component assembling field will be replaced by robotic systems. Perhaps the most documented and visible industry to be effected has been automotive manufacturing. However, other industrial concerns in aerospace, shipbuilding, textiles, forging, die casting, electronics, small appliances and related industries are all rapidly expanding the use of robotics or related technologies in their respective manufacturing areas. Most of these industries utilize basic line assembly manufacturing techniques. For this reason current generation robotic manufacturers have adopted particular configurations and general characteristics which are common to 90% of the present robot population. These characteristics are governed by requirements conforming to the basic underlying purpose for robotics--increased productivity. Robotics technology is supplementing or replacing the human worker/operator where the subject process;

- requires repetitive action beyond the capabilities of humans;
- is time or labor intensive;
- environment is hazardous to humans;
- is quality/precision controlled, and/or
- requires speed of action in excess of human capabilities.

Some or all of these requirements are commonly found on any industrial assembly line. Therefore, robotic systems have evolved into mechanical entities maintaining characteristics which are basically stationary, manipulatory, unitary and application-unique. The aforementioned characteristics are industrially efficient, economical and utilize but a small portion of space on the assembly line. For these reasons, little attempt has been made to further robotic evolution as applied to these characteristics. Robotic evolution has now entered an area of increasing capabilities through the use of artificial intelligence and the addition of sensory perceptions. To gain a better understanding of this technology, the following paragraphs will cover some of the fundamentals of robotics and robotic systems.

A robot consists of three basic components: a controller, a manipulator, and an end effector(s).

1. Controller. The controller functions as the brain and nervous system of the robot and consists of any programmable device from a rotary drum switch to a full computer. The controller not only directs the robot through its programmed moves, but in more sophisticated systems with the capability of artificial intelligence, it integrates the robot with ancillary machinery, equipment and devices. Monitoring processes and making decisions based on system demand while at the same time reporting to a supervisory control are also within its capability. There are three types of programming; walk-through, lead-through and plug-in. Major factors utilized in determining the type required are; cost, operational environment, task variance, and the utilization of single or integrated units tied to a specific controller.

a. Walk-Through Programming. This type of programming requires the operator to physically manipulate the unit through the desired sequence of events. The robotic unit records each motion and joint position. Upon program execution these motions and positions are replicated in sequence. Ease of programming is an obvious advantage, however, operator errors and subsequent reprogramming may offset this apparent advantage.

b. Lead-Through Programming. This type requires the operator to utilize a "teaching box," or remote programming unit, to guide the manipulator through the desired sequence of events. Various motions and positions are again recorded and upon program execution, are replicated. Ease of programming by remote control contains advantages when working with units located in hazardous environments such as radioactive material handling, space systems and remote undersea systems. However, operator errors and subsequent reprogramming, again, are disadvantages.

c. Plug-In Programming. This type consists of placing a prerecorded program into the robotic unit. This method is by far the fastest and easiest programming method available today. It also tends to be the most expensive.

2. Manipulator. The manipulator consists of a base and one or more arms plus a power drive (pneumatic, hydraulic or electric). The specific type of drive system is determined by parameters set forth by the customer, usually based on cost, lifting requirements, industrial operational environment and plant infrastructure. The manipulator is the component that provides movement in up to six degress of freedom. The movement can be described by four types; cartesian, cylindrical, polar (spherical), and anthropomorphic (jointed arm). The specific required motion is determined by the operating envelope and lifting requirements. Graphic illustrations of these motions are shown in Figure II-1. Depending on the controller, movement can be servo or non-servo controlled.

a. Servo Controlled. Servo controlled robotic units, also known as continuous path, are characterized by smooth precision operation. These robotic systems typically have internal sensors which monitor unit speed, velocity, acceleration, force and torque. The measurements are compared to predetermined operational parameters and adjustments are transmitted to the servo controller for correction. Depending upon the servo controller, the internal sensors and the basic unit characteristics, a servo controlled robotic system may operate at high speed and be capable of precision work. The application of servo controlled units to the industrial sector has been somewhat limited due to their great expense and limited adaptability to changes in the manufacturing process. Functional servo controlled robotic units are therefore limited to operations where predictive automation can occur.

b. Non-Servo Controlled. Non-servo controlled robotic systems, also known as point-to-point, are the least complicated robotic units. These move

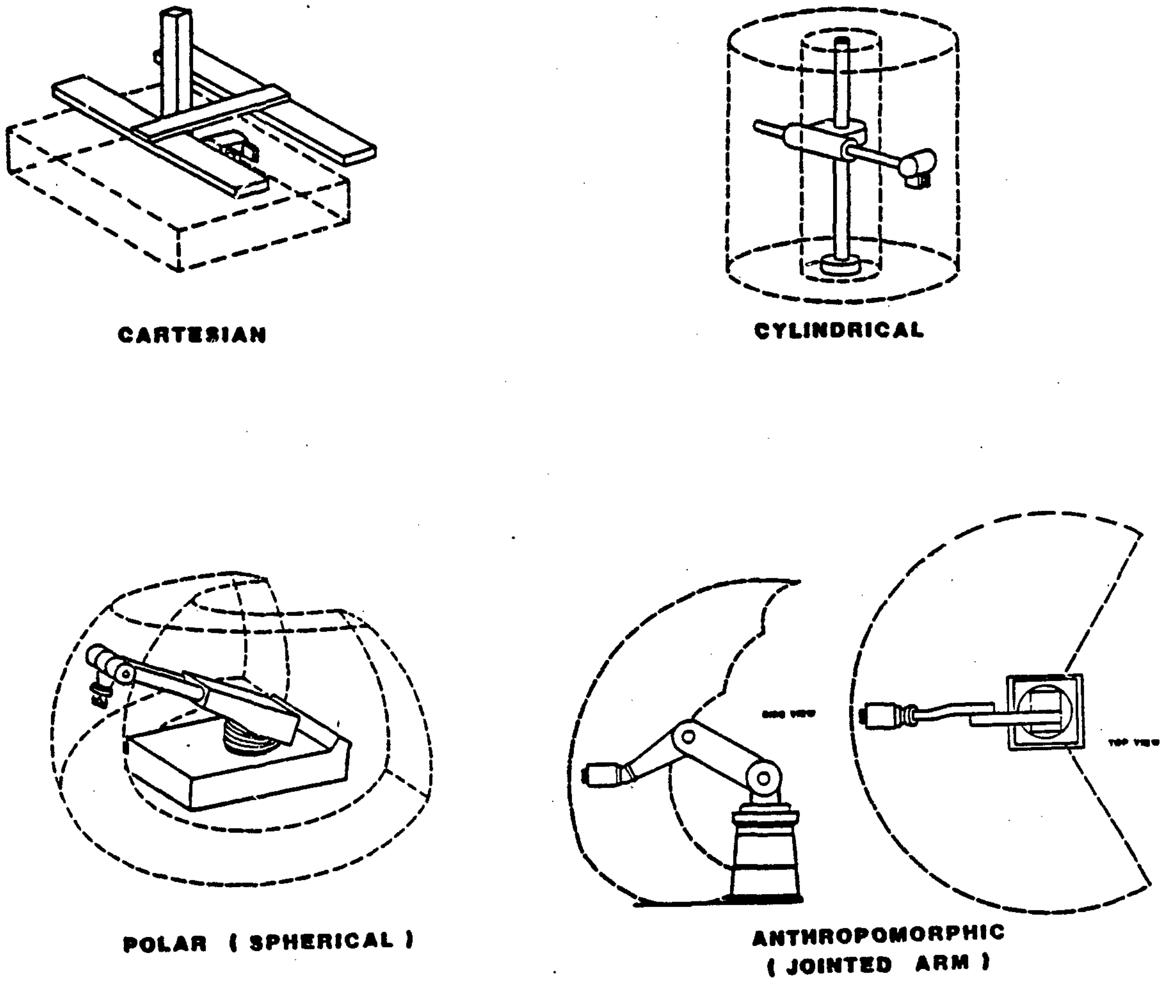


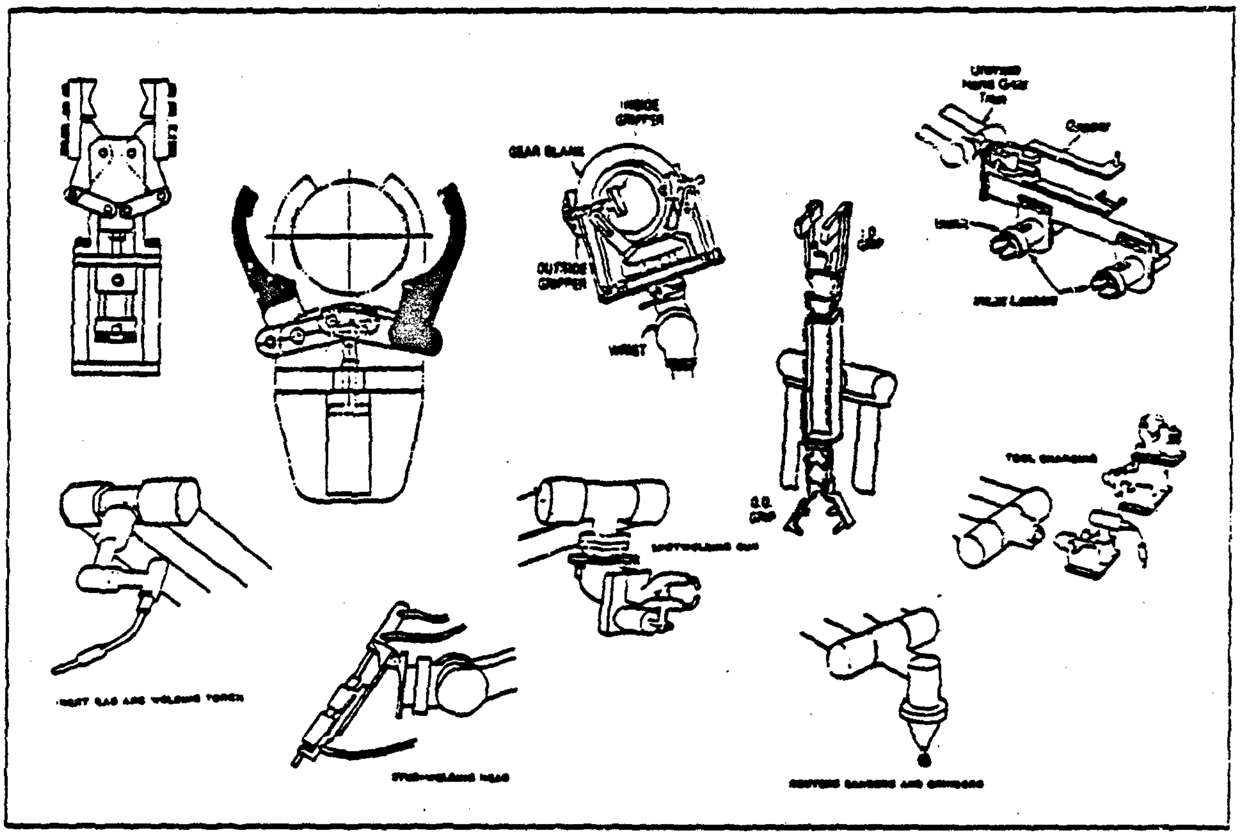

Figure II-1
ROBOTIC MOTION

in an open loop fashion between two exact end points on each axis or along predetermined paths in accordance with fixed sequences. These robotic systems can operate over an infinite number of points enclosed by their operational envelope. Non-servo controlled robotic units are given start and end points on each axis which must be passed, there is little or no control of end effectors between these points. Technically, controlled trajectory is possible on a non-servo controlled system only if the unit is given the coordinates of all points lying between the start and end parameters. This specific type of programming will allow the robotic system to perform motions such as straight line, circles, etc. Inherent limitation in the control sequence characteristics of non-servo controlled robotic units limit application of these units to predefined special functions.

3. End Effector. An end effector is either a device for material handling (gripper or hand) or a tool. The gripper, a mechanical, vacuum or magnetic device, is generally limited at present to two position operation, i.e., open/closed, on-off. It is one of the most limiting factors in universal robotic utilization, due to the lack of hand programmability. Extensive research and development is being done to produce a gripper that can handle a wide assortment of part configurations. The variety of tools that can be adapted for robotic application is almost unlimited. Present tools include welding heads (torch, gun, etc.), spray part heads, drills, routers, sanders, grinders, etc. An assortment of grippers and tools is depicted in Figure II-2. End effectors have four motions; sliding, roll, pitch, and yaw. These motions are graphically illustrated in Figure II-3.

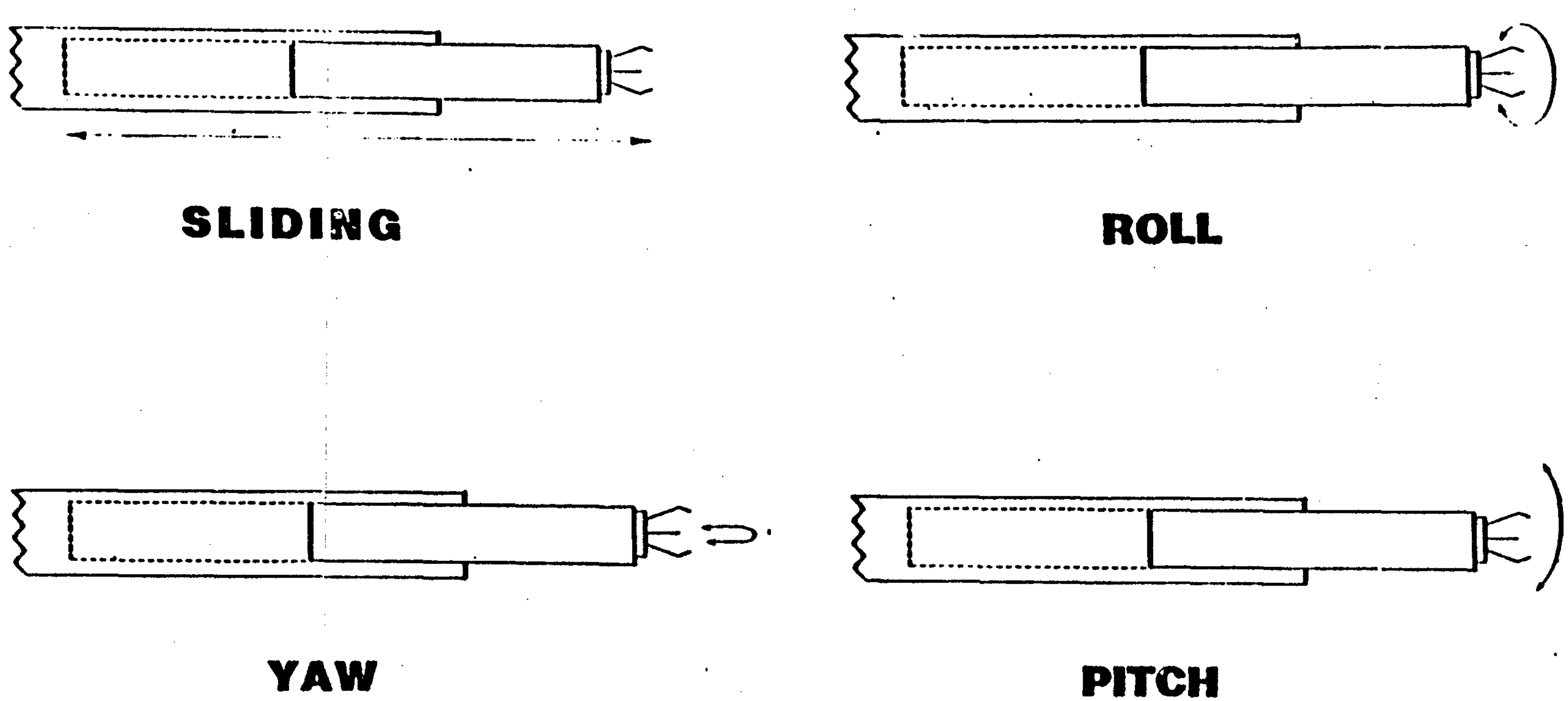
## C. Robotic Functional Categories

There are three general robotic functional categories; pick and place, general purpose, and closed loop. These categories refer to the level of sophistication built into each of the robotic systems.




GRIPPERS AND TOOLS

Figure II-2




END EFFECTOR MOTION

1. Pick and Place Units

The least sophisticated robotic systems are the pick and place systems. The functions of these units are limited to picking up an object, transporting the object to a predetermined location and placing the object in that location. Robotic systems falling into this category are capable of high speed and cannot readily be reprogrammed to operate in varied sequence. Machine loading/unloading, die casting, and forging are typical examples of functions these systems perform.

2. General Purpose Units

These units are not specialized to any one application. They can be equipped with a variety of components and can be programmed to perform various tasks. Typically, this unit is customized by the producer to specifications provided by the customer. Applications include such functions as: industrial coating, welding, polishing, deburring and drilling.

3. Closed Loop Units

This robotic system is the most sophisticated type. These systems utilize a variety of advanced sensory inputs to adjust unit performance to specified parameters. Again, this system is tailored by the producer to customer specification. Closed loop systems may utilize some degree of binary logic artificial intelligence to accomplish respective tasks. Robot technologies utilized in space exploration are a prime example of closed loop systems.

## D. Artifical Intelligence

The term "artificial intelligence" has been defined as being "the science of making machines do things that would require intelligence if they were done by men."[2] At present no systems exist which can even remotely be compared to human intelligence.

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2Dr. Marvin Minsky, President, American Association for Artificial Intelligence

Modern artificial intelligence rests on the foundation of binary logic. All programming can be delineated into simple go/no-go decisions. The ability to comprehend abstract reasoning or draw from intuitive thoughts does not yet exist in artificial intelligence. Some individuals argue that this form of intelligence may never exist in entities driven by binary logic. Nevertheless artificial intelligence can be viewed as a logical (mathematical) sequence of event determined by preordained operational parameters.

The prospects of a computer building a human-like data bank are, at present, minimal. No computer can assimilate or understand the myriad of information contained within a single human mind. Computers do not contain any information about themselves. Without such information they cannot "understand" themselves and, therefore, fail to acknowledge the existence of themselves. Without these "self-models" computers cannot conceive of the existence of others. Basic questions regarding existence, functions, etc. cannot be considered until knowledge of oneself is known.

Artificial intelligence, used in its present form and context, refers to the use of data and operational parameters stored within a computer for directing the actions of robotic systems. These data may be stored in the form of: random access, magnetic tape, magnetic disc and/or bubble memory, etc. Thus, any robotic unit which utilizes the data stored within a computer can be said to operate via use of artificial intelligence.

In laboratories today, experiments are being conducted in the use of "basic script" or analogical reasoning (expert systems) to augment basic data and operational parameters stored within a computer. Research, presently being conducted at Carnegie-Mellon University by Jaime G. Carbonell, sets forth the basic premise the problem solving and learning are inalienable. In other words, when encountering a new problem situation, a person is reminded of past situations that bear strong similarities (at different levels of abstraction) to the present situation. This type of reminding experience serves to retrive behaviors that were appropriate in earlier situations, where upon past behavior is adapted to meet the demands of the current situation.

Commonalities among previous and current situations, as well as successful applications of modified plans can serve as the basis for generalization. Similarly, performing an inappropriate behavior in a new situation can lead to discrimination (among the ways in which situations are organized in memory and/or the mechanisms that adapted an existing plan to a new situation). However, a reactive environment, one that informs the problem solver of success, failure or partial success, is an absolute requirement for any generalization or discrimination process to apply. Therefore, problem solving by analogy and experimental learning are inalienable components of a unified cognitive model. Analogical problem solving exploits knowledge of plans indexed under situations similar to the current one, generating new purposive behavior potentially relevant to future problem solving. The learning component creates the memory structure to encode experimental knowledge that enables the problem solver to retrive and compare relevant situations from memory.

## E. Sensory Perception

A growing field of interest in robotics is that of sensory perception. True artificial intelligence must utilize information selectively obtained from external sensors. Industry has invested enormous amounts of manhours and fiscal resources into development of practical sensor systems. Only one system has evolved thus far which has practical application in the industrial environment--visual. However, two more systems are presently in laboratory development and significant breakthroughs could lead to utilization in the near future--tactile and audio reception/transmission.

1. Visual Sensory Perception

Visual images represent major sources of information; providing a robot with a visual system is fairly uncomplicated. However, in order for a robot to comprehend what it is viewing a degree of artificial intelligence is required. The most important development in visual systems has occurred within the last five years with the introduction of the imager chip, also known as the charged-injection device (CID), charged-coupled device (CCD), or the photodiode array. This chip is capable of collecting light 80 times more efficiently than photographic film. Furthermore, it can detect exceedingly faint traces of light and is capable of distinguishing subtle differences in intensity.

The chip offers vision with geometric precision not attainable with other optical devices. As a result of this breakthrough, precision control in three dimensional vision industrial processes are now a reality.

The imager chip operates on principles first identified in the latter part of the 19th century. These principles state that various metals emit electrons in varying intensity under different light wavelengths. The chip is composed of a multitude of picture elements (known as pixels) manufactured utilizing a variety of different metallic properties. These pixels absorb photons and capture and store the electrons knocked out of their orbits by the impacting photons. The electrons are transmitted to receivers such as television screens or magnetic tape. The energy and number of photons received represent light intensity of the captured screen; the liberated electrons represent the light intensity electronically.

The great precision with which the pixels are arranged on the imager chip make possible phenomenal geometric accuracy of the new images. Inspection of manufactured items can now be done with precision unattainable before, down to two millionths of an inch. This assures astounding quality control.

Speed in visual processing is of the utmost importance in order to deal in "real time" computer logic, an important asset in manufacturing. The imager chip, along with extraordinary precision, is capable of processing more than 20 pictures per second. This indicates that inspection rates of more than 72,000 parts per hour are now possible.

In order for robotic systems to understand what they are seeing, images must be structured to be comprehensible in binary logic. Vision depends upon image perception, distinctive characteristic extraction and image input analysis.

Image perception requires that sensors allow perception of a signal. These sensors may be divided into two types -- active and passive. The active sensors emit energy (in the form of light waves or sound waves). This energy is reflected off the object in question and is received by the sensor. These reflections are then analyzed and processed (as explained later). Passive sensors utilize external illumination to provide the reflective energy. These sensors then extract and process the features in the same manner as active sensors.

Once the sensor has captured the image, distinctive characteristics or features are extracted. This process involves the segmentation of an image into different "regions." Regions are collections of characteristics which have similar properties such as color, intensity, brightness and/or texture. Points with similar characteristics generally belong to the same object in an image. The characteristics are then segmented into distinct regions. Segmentation techniques cannot separate every object in an image into understandable regions. Therefore, distinctive characteristic extraction requires a prior knowledge of the image. The image, now segregated into general regions with similar characteristics, is further defined by "boundary line edge detection." In this process, variations in intensity, color and/or texture at transit boundary areas are further defined and identified. These points are then used to identify other boundary line points of similar quality. This process is known as "edge characteristic inclination function." These points are then linked together to form an outline of the object in question in a process known as "similar edge characteristic linking." Distinctive characteristic extraction is now complete. The robot has obtained an outline of the object, is aware of color, texture and intensity and must now analyze the input.

Image input analysis requires the robot to have prior knowledge of the object in question. The general outline, color, texture and intensity of the image is stored in binary logic for comparison to information, specifications and parameters already on file. This comparison may take the form of a template comparison, random dimension search or a mass/volume search. Upon identification of similar characteristics, the image produced is compared to the image stored. In this manner the robot may determine whether the object in the scene is positioned correctly, of adequate quality, etc. It is of utmost importance that the reader realize that the robotic unit never truly understands what it is seeing; it only compares its image input to stored images. All present robotic visual systems require a prior knowledge of what the image should look like. Deviation from acceptable parameters are considered defective and the object is rejected.

2. Tactile Sensory Perception

To increase the efficiency of robotic systems utilized in the manufacturing field, other senses, supplementing vision, will be required. Tactile perception will be of importance for close up assemble work where vision may be obscured by end effectors or other objects. Robotic systems will also require this perception to assist with sensory feedback for use in grasping delicate objects and kinesthetic feedback as it relates to improved motion control.

The lack of sensors with adequate resolution and sensitivity have hampered efforts to fully utilize tactile perception. Recent advances in the development of tactile sensors embedded in "artificial skin", made of silicone rubber, promise to further this area of interest.

Practical tactile sensors have recently become available on the commercial market. They operate in a manner similar to the tactile corpuscle array. The artificial sensory array has about the same dimensions of the human finger tip. It contains 256 pressure sensitive switches arranged in a 16x16 grid pattern. As the robotic "finger" contacts an object the switches connect forming a pattern recognizable to the robotic system. This sensor has demonstrated the ability to distinguish between six objects with resolution comparable to that of the human finger. This array is constructed by sandwiching a porous material between the silicone rubber and a flexible printed circuit board. The silicone rubber is impregnated with graphite allowing it to conduct along 16 parallel lines oriented at 90° angles. The two layers (silicone rubber and printed circuit board) are separated by a thin porous material. When compressed they make contact at intersection points forming a sensory array. Pressure patterns are then transmitted to the robotic unit.

Upon reception of these patterns, the robotic system performs an image analysis search similar to the visual system. Comparisons are made via template, random dimension or weight. Identification results when similar characteristics are identified.

A recent development in the tactile sensory field involves the utilization of fiber optics in robotic end effectors. The process involves measuring the deflection of light traversing the fiber optic cable from generation source to terminal point. As light is deflected (by grasp) less light is absorbed at the terminal point. By increasing the difference from generation point to terminal point, the amount of pressure exerted can be measured.

### 3. Other Sensory Perceptions

Along with visual and tactile sensors, scientists are working on a multitude of other perceptions. These perceptions tend to have an predisposition toward being closely allied with the five human senses of: sight, tactile, audio (speech and hearing), and olfactory. While work has progressed, it has not reached the level of proficiency attained by visual and tactile. This, however, may only be a matter of time.

Audio speech and hearing work basically on the same principles in reverse. In hearing, sound is converted from waves to a mathematical formula. This formula then converts into simple binary logic. The formula "solution" may then be inputed into the robot for a search and comparison. Upon locating an appropriate number or group of numbers the word "meaning" is "understood" and actions may then insue. Speech entails the appropriate response to inputed words or actions. Binary logic selects the appropriate response to an input and then converts this to a mathematical formula. This is transmitted to a "voice box" where audible sounds are produced.

Olfactory preception works basically on the same principles as that of a smoke detector. Minute particulates of matter enter into a unit where they are analyzed as to specific atomic composition. This composition or atomic structure is then transformed into binary logic and appropriate responses can then occur.

Special sensors are being developed for specific applications. These sensors are developed for use typically in hazardous environments where extremes in pressure, illumination or hazardous materials are the norm. These sensors are developed to protect the robotic unit or human operator from exposure to extremes beyond operational parameters.

## F. Industrial Robotic Growth Potential

The University of Michigan recently conducted a study in concert with the Society of Manufacturing Engineers (SME). The study, utilizing Delphi forecasting techniques, anticipated robotic trends in areas such as: growth potential, types of robotic units, levels of required technical sophistication, application/utilization classes, areas of projected worker/operator displacement, etc. A representative sample of robotic system manufacturers (12) and robotic users (48) returned submitted questionnaires. Based upon these responses, preliminary data was compiled and projections were presented on eight areas of industrial (manufacturer/user) interest. These areas and short subjective discussions are presented below.

- Annual Shipments of Robotic Units Produced in the United States

  Projections, based upon compilation of manufactuer/user data extracted from the aforementioned responses, indicates that the gradual increase in unit shipments will continue to 1984. Growth to minimum shipments of 6000 units will be achieved by 1985. Forecasts indicate that by 1990 shipments will surpass 10,000 units and will roughly double every five years.

- United States Produced Robotic Systems as a Share of the United States Market

  Data indicates that a favorable situation is/or has developed for United States robotic manufacturers. Barring serious swings in the world dollar value, domestic robotic system manufacturers are expected to capture a minimum of 75% of the United States market by 1985. By 1990 domestic producers are forecast to increase their share to 79%.

- Robotic Systems Attaining the Capability for Self-Generated Propulsion

  By 1985 it is anticipated that major aerospace firms will lead all other industries in applications utilizing units capable of self-propulsion. Sales volumes for aerospace firms are expected to equal demand from all other industries. Steady growth is expected in this area through the 1990's.

- Share of the Market Captured by Robotic Units with Adaptive Controls

  In 1983, 5% of the robotic population utilized in the aerospace industry will attain advanced levels of adaptive controls. By 1985, 5% of all industrial robotic units will utilize adaptive controls. The aerospace and electrical/electronics industry will attain levels projected to be 20%. Lagging three to five years behind will be the light manufacturing and automotive industries.

- **Robotic Systems Utilizing Visual Perception**

  Projected trends indicate that robotic systems with visual capabilities will capture 15% of the market in the aerospace and electrical/electronic industries by 1985. The automotive industry is projected to utilize only 10% during this time frame. Data indicates that visual equipped robotic units will experience exponential growth after 1990 with 25% of all units being so equipped. It is anticipated that leadership in this field will be maintained by the aerospace industries with the automotive industry following closely.

- **Projected "Scene Analysis" Capabilities**

  Robotic units, utilizing some degree of artificial intelligence for scene analysis in complex scrambled parts handling, will account for 10% of domestic purchases by 1985. During the 1990's this percentage is expected to increase to, at minimum, 15%.

- **Anticipated Weight of Parts Manipulated**

  In 1980 the industrial average weight of parts manipulated was 20 pounds. Decreases in this average are projected for the automotive and electrical/electronics industries by 1985. The average weight will increase for all other industries during this time frame. Projections for the 1990 period indicate that weights will stablize at optimum levels for the automotive, electrical/electronic, light manufacturing and aerospace industries. Increases in projected weight of parts manipulated in the heavy manufacturing and casting/foundry industries will continue.

- **Projected Trends in Computer Equipped Robotic Units**

  Half of all robotic systems sold on the domestic market in 1985 will be computer equipped. The aerospace industry will continue to be the leading consumer for these robotic units followed by the automotive industry and the electrical/electronics industries. The light manufacturing sector will catch up to the automotive industries by 1985. Four out of five robotic systems sold to industry in the 1990's will be computer equipped except in the casting/foundry and heavy manufacturing fields. These industries will trail other industries until well after the 1990 time period.

The Robotics Institute of America (RIA) commissioned a second study (recently completed) to determine specific data on the international robotic population. The study requested information regarding the specific number and types of robotic units present in a country, the extent of government involvement and support, robotic standards, leading R&D organizations and universities, union attitudes and the potential for future robotic growth. Information was supplied to the International Coordinators Group representing 19 countries. In addition, the Japan Industrial Robotic Association (JIRA) supplied information on activities in that country and Daiwa Securities America of New York supplied approximations for the Soviet Union.

Compilations of the data indicate that the largest concentrations of robotic systems are used in the welding, assembly and machine loading/unloading areas.

Tables II-1 and II-2 presented on the following page, indicate the present international robot population and projected trends in robotic population growth. It should be noted that Japan's definition of a robotic unit differs from that used in the United States in that is includes simple pick and place units.

## G. Sociological Impacts

The increasing commercial use of robotics to improve productivity has in some cases caused job displacement and unemployment due to a resultant shift in job requirements. It is anticipated that the utilization of robotics in factories will significantly reduce the number of hazardous and demeaning work stations while providing an overall improvement in productivity and product quality. Additionally, job satisfaction is expected to improve and decreases in work related accidents are forecast.

Contrary to the Ludd[3] philosophy it is predicted, both by industry and government, that resultant job displacement and unemployment due to factory automation will be minimal. Data indicates that only 6 percent of displaced workers can expect to be terminated. This figure represents a maximum of 20,000 individuals. New jobs created by factory automation and resultant service industries are expected to number from 70,000 to 100,000. It must also be understood that maintaining the present status quo of minimal factory productivity

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[3]Edward Ludd was a Leicestershire workman who destroyed stocking frames in 1799 and was the spiritual progenitor of the most opprobrious of antimachine movements.

## TABLE II-1: INTERNATIONAL ROBOT POPULATION (1980)

| COUNTRY | TYPE A | TYPE B | TYPE C | TYPE D | TYPE E | TOTAL |
|---|---|---|---|---|---|---|
| Japan | — | 6,899 | — | 7,347 | 53,189 | 67,435 |
| USA | 400 | 2,000 | 1,500 | 200 | — | 4,100 |
| West Germany | 290 | 830 | 200 | 100 | 10,000 | 11,420 |
| France | 120 | 500 | 2,000 | 6,000 | 30,000 | 38,620 |
| USSR | *— | — | — | — | — | 3,000 |
| Switzerland | 10 | 40 | — | — | 8,000 | 8,050 |
| Sweden | 250 | 150 | 250 | 50 | 100 | 800 |
| Norway | 20 | 50 | 120 | 20 | 50 | 260 |
| Czechoslovakia | 150 | 50 | 100 | 30 | 200 | 530 |
| Great Britain | *— | — | — | — | — | 371 |
| Poland | 60 | 115 | 15 | 50 | 120 | 360 |
| Denmark | 11 | 25 | 30 | 0 | 110 | 176 |
| Finland | 35 | 16 | 43 | 22 | 51 | 167 |
| Belgium | 22 | 20 | 0 | 0 | 82 | 124 |
| Netherlands | 48 | 3 | 0 | 0 | 30 | 81 |
| Yugoslavia | 2 | 3 | 5 | 0 | 15 | 25 |
| TOTAL | 1,418 | 10,701 | 4,293 | 13,819 | 101,947 | 135,519 |

Type A: Programmable, servocontrolled, continuous path
Type B: Programmable, servocontrolled, point-to-point
Type C: Programmable, nonservo robots for general-purpose use
Type D: Programmable, nonservo robots for diecasting and molding machines
Type E: Mechanical transfer devices (pick-and-place) (U.S.A. defined as non robotic)

* Independent approximations

## TABLE II-2: FORECAST OF ROBOT GROWTH

| COUNTRY | 1985 | 1990 |
|---|---|---|
| Japan | 16,000 | 29,000 |
| USA | 7,715 | 31,350 |
| West Germany | 5,000 | 12,000 |
| Switzerland | 600 | 5,000 |
| Sweden | 2,300 | 5,000 |
| Norway | 1,000 | 2,000 |
| Great Britain | 3,000 | 21,500 |
| Poland | 200 | 1,200-1,500 |
| Denmark | 110 | 250 |
| Finland | 950 | 3,000 |
| Belgium | 150-200 | — |
| Yugoslavia | 100-150 | 300 |

and profitability will force factory owners to close unprofitable facilities, potentially affecting hundreds of thousands of American workers.

The impact of robotics on long-term unemployment is centered upon several factors which will ultimately affect outcome prediction. The factors are:

- The speed of new technology implementation
- Inherent complexity of the unemployment issue
- Lack of specific and comprehensive data regarding automation net impact.

Potential barriers and constraints may slow the implementation of robotics. This reduction in the utilization of robotics will decrease the impact on employment by allowing time for retraining, job shifts, etc. Conversely, rapid utilization would result in increased unemployment in the short-term until retraining and/or job transfers could be implemented.

The constraints or barriers may be institutional, financial, historical, etc. They include human and institutional resistance to change, union activities, capital investment considerations, software/hardware costs and the lack of qualified individuals in the robotic field.

The rate of unemployment and the number of available jobs in the United States are highly complex issues. A multitude of factors affect both issues simultaneously. It is, thus, difficult, if not impossible, to isolate the impact of robotics alone on employment.

The lack of specific and comprehensive data regarding the net impact of factory automation renders it impossible to arrive at a valid conclusion regarding robotics vs. employment. Data that is available includes only estimates or projections within a given company, plant or locality. Estimates are based upon aggragate changes in employment, disregarding adjustment for previously described factors.

Not withstanding the aforementioned, the Office of Technology Assessment (OTA), the Department of Labor's Bureau of Labor Statistics (BLS) and the Society of Manufacturing Engineers (SME) in cooperation with the University of Michigan all predict a positive growth pattern relating to employment, due to increased automation, in the long-term.[4] Rapid technology implementation is expected to create short-term unemployment/job displacement which is anticipated to be offset by robotic service industry job creation.

In summation, the sociological impact of emergent robotic technologies will displace some workers in the short-term, but will provide increased employment in the long-term. The degree of impact is expected to vary subject to the rate of technological implementation.

## H. Summary

State-of-the-art robotics are generally adapted to meet the needs of industrial concerns. These robots are limited by their lack of mobility and adaptability.

Robotic motion falls into four categories - cartesian, cylindrical, polar and anthropomorphic. The end effectors add four more degrees of freedom - sliding, roll, pitch and yaw. However, few industrial robots exist today which are self-propelled.

Recent developments in the laboratory have greatly expanded the use of artificial sensory perception. Visual systems are now common place among simple robots. The development and use of other sensors is proceeding at an astounding pace. Tactile, audio (reception and transmission), olfactory, proximity, range, magnetic-field and radioactivity sensors are all being developed and will be exploited as soon as they are commercially practical.

Artificial intelligence still represents a major problem area in that the assimilation and codification of new information still must be done by a human operator. However, recent developments in laboratories suggest that this problem

[4] Industrial Robotics, A Delphi Forecast of Markets and Technologies

area may be diminishing. Development and exploitation in the use of analogical problem solving may augment stored operational parameters and assist in attaining true artificial intelligence.

It has been predicted that adoption of robotic units in the factory will affect employment. However, all studies indicate that factory automation will provide an overall increase in the number of jobs with an associated decrease in demeaning and/or hazardous work areas.

Chapter III

## Navy/Industry Unique Requirements

### A. General

The basic underlying purpose of all present industrial robotic systems is to increase efficiency and productivity by eliminating or enhancing the human worker/operator where the subject process:

- is high volume;
- is repetitive;
- is time or labor intensive;
- environment is inhospitable to humans;
- speed required is beyond human capabilities; and/or
- precision/quality required is beyond human capabilities.

A vast difference in philosophy and terminology exists when military productivity and industrial productivity are compared. Both sectors seek to allocate scarce resources efficiently and effectively, however, the initial boundary condition and final productive outcome are vastly different.

#### 1. Industrial Productivity

Industrial productivity seeks to efficiently allocate scarce or costly resources (i.e., labor, production facilities, raw materials, etc.) to lower final unit cost through increased output or decreased waste. This is productivity in the classic sense.

#### 2. Military Productivity

The military seeks to produce weapons systems which are economical to support and maintain and which cause an adversary to expend excessive amounts of his scarce resources (i.e., manpower, fiscal, materials, etc.) as a result of the effects of, or to defend against, these weapons systems. The cruise missile is a classic example of "military productivity". For a relatively small investment the United States will force the Soviet Union to expend large amounts of resources to provide effective air defense coverage. These Soviet resources must be reprogrammed out of planned or present expenditures to the detriment of other programs. Therefore, military productivity seeks to provide weapons which will:

- be economical to acquire, maintain and support;
- be efficient and effective; and
- provide an unacceptable imbalance in an adversary's defenses causing scarce resources to be reallocated to the detriment of existing or planned programs.

The reallocation of scarce resources has its basic roots in the "guns and butter" classic economic model. This model states that a nation has a finite set of scarce resources. Within that set, a nation allocates resources to civil needs and military needs. An increase in one of the constants must be offset by an associated decrease in the other constant. Thus, as military needs increase (due to an unacceptable imbalance in defense), civil resources decrease. This decrease in civil resources (consumer goods) may cause unrest in an adversary's country, thus, doubling the effect of military productivity.

Major differences exist in requirements and/or characteristics unique to the varied operational environment between potential naval robotic users and industrial robotic users. These differences in requirements and characteristics are largely related to the differences in the industrial and naval operations listed below.

| INDUSTRY | NAVY |
|---|---|
| - Product Manufacture | - Existing Product |
| - High Volume<br>High Speed<br>Repeatable | - Case Basis<br>Remanufacture<br>Repair<br>Replace |
| - Fixed Workstation | - Moving Workstation |
| - Controlled Environment | - Weather Sensitive<br>Unstable Platform |

## B. Industry Unique Requirements

For the purposes of this assessment, industrial robotic users addressed were those involved in manufacturing or assembling of a product (vice transportation, warehousing, services, etc.). The use of basic line assembly techniques dictate that equipment designed to assist in manufacturing be capable of handling a high volume/high speed work environment concurrently maintaining precision/quality control with an absolute minimum of "down time." The manufacturing production facility site is immobile and sustains controlled operational environments where parameters regarding atmospheric and chemical norms are constant. Fixed workstations process resources which flow past at predicted rates on a defined path, in a defined area. The almost total control of environmental parameters and manufacturing norms indicate that predictive maintenance can occur at regulated intervals reducing unanticipated delays and shut-downs due to system malfunction. Constant unit supervision by human operators is being replaced by sensor technology due to the generally non-hazardous nature of products assembled or finished at production sites. Total manufacturing of products (assisted by computer design and monitoring) can be accomplished without direct human exposure to the cycle.

## C. Navy Unique Requirements

The application of robotics, generalized to include advanced automation and artificial intelligence, to naval aviation combat operations, weapons systems maintenance, repair and remanufacturing centers and direct operational support can significantly affect operational response capabilities.

### 1. Depot Level Maintenance (D-Level)

Naval Air Rework Facilities (NARF's) provide the major portion of naval aviation depot level maintenance. The comparisons digress when the basic functions and end products are identified in a comprehensive manner. NARF's are stationary shore-based facilities. Tasks include the repair-remanufacture of aircraft, aircraft weapons systems, subsystems and/or components. Inherent in this function is basic disassembly of the product, repair, and remanufacture. Due to the nature of this operation, industrial assembly line techniques have not been widely adopted. Tools and material are transported to the units under going repair or remanufacture. This negates industrial requirements for high volume/high speed stationary equipment and instills requirements for mobile precision/quality equipment to be utilized on a case basis. The prevelant atmospheric environment (i.e., humidity, stability, chemical, etc.) is defined and poses no problems which would not arise in industry. The direct transfer of technology from industrial concerns to D-Level maintenance (NARF's) could be and is being accomplished with a minimum of new technological developments. This is primarily true in the areas of numerically controlled machining, inspection and precision calibration.

2. Intermediate Level (I-Level)

At I-Level naval aviation maintenance disgression from industrial norms becomes much more apparent. Aircraft Intermediate Maintenance Departments (AIMD's) operate both ashore and afloat, at air stations and aboard carriers respectively. Equipment must be mobile while concurrently maintaining a high degree of precision or quality control. Further, due to the at-sea requirement, equipment must provide maximum flexibility of operation for a minimum size and be otherwise shipboard adaptable. Environmental control, assured in industry or depot level maintenance facilities, is no longer available. Thus, equipment must be developed which can provide assurance of motion compensation ability and be "RAD HAZ"[1] free while maintaining maximum protection from salt water corrosion. Due to the nature of the tasks being performed total computer control may not be desirable. Manual

1 Electromagnetic Radiation Hazard

observation and override capabilities must be integrated into unit design. The at-sea requirement, due to limited space and supply considerations, additionally imposes the further considerations that units be compact, air-transportable, have a high "payload" to weight ratio and be self-stowable. These at-sea requirements and characteristics will continue anytime that equipment is (or may be) based onboard ships.

3. Organization Level (O-Level)

Organizational level aviation maintenance resides within deployable fleet squadrons and detachments. O-Level requirements stress minimum size/weight characteristics with shipboard adaptability as a prerequisite. All equipment at this level must be compact and deployable with aircraft squadrons. Minimum size, maximum flexibility and shipboard adaptability are prerequisit considerations which must be viewed as constraints upon systems and/or technologies which may be transferable from industry to naval usage.

4. Operational Support

The Operational Support category, generalized to include handling, arming, fueling, landing, launching, and similar operations, as well as the functions of some combat systems and subsystems, imposes the most strigent requirements upon equipment and technology which may be developed to function at sea. Again, as with O-Level maintenance, minimum size, maximum flexibility and shipboard adaptability requirements override most other considerations. Exposure to hostile environments will be more likely for this category. Therefore, equipment must be protected against adverse weather situations which may include violent storms and associated shipboard stability problems. Exposure to corrosive and sometimes harsh environmental elements will be severe. Reliability and fault tolerant designs will be of importance when dealing with systems designed to augment human capabilities in hostile environments (natural and combat induced).

## D. Summary

Industrial robotic characteristics stress requirements associated with the manufacture of large numbers of identical semi-finished or finished products. These characteristics are:

- high volume/high speed
- precision/quality control
- fixed workstations
- controlled environments

Naval robotic users must stress characteristics associated with the remanufacture, repair, replacement and operation of systems, subsystems or components on weather influenced unstable platforms. The unique operational environment dictates special consideration be given at-sea environmental requirements driving system design.

Meridian Corporation conducted an empirical qualitative study of potential or existing robotic applications and characteristics. Industrial and academic representatives as well as active and retired officer and enlisted fleet personnel provided input on various robotic characteristics and their respective applicability in a variety of functional areas. Impact charts similar to Figure III-1 were prepared from each input. Figure III-1 is representative of the processed concensus of all inputs.

The level of applicability of a wide variety of robotic characteristics in industrial and naval aviation applications are indicated. Individuals were requested to rate each characteristic from 0% to 100% applicability to each environment. Since no specific numerical value could relate to "potential" applications, semantic guidance was provided as follows: ranking of 0%, "none", 1% to 25% "little", 26% to 50% "some", 51% to 75% "significant" and 76% to 100% "high".

ASSESSMENT OF POTENTIAL

FOR EXISTING ROBOTIC APPLICATIONS

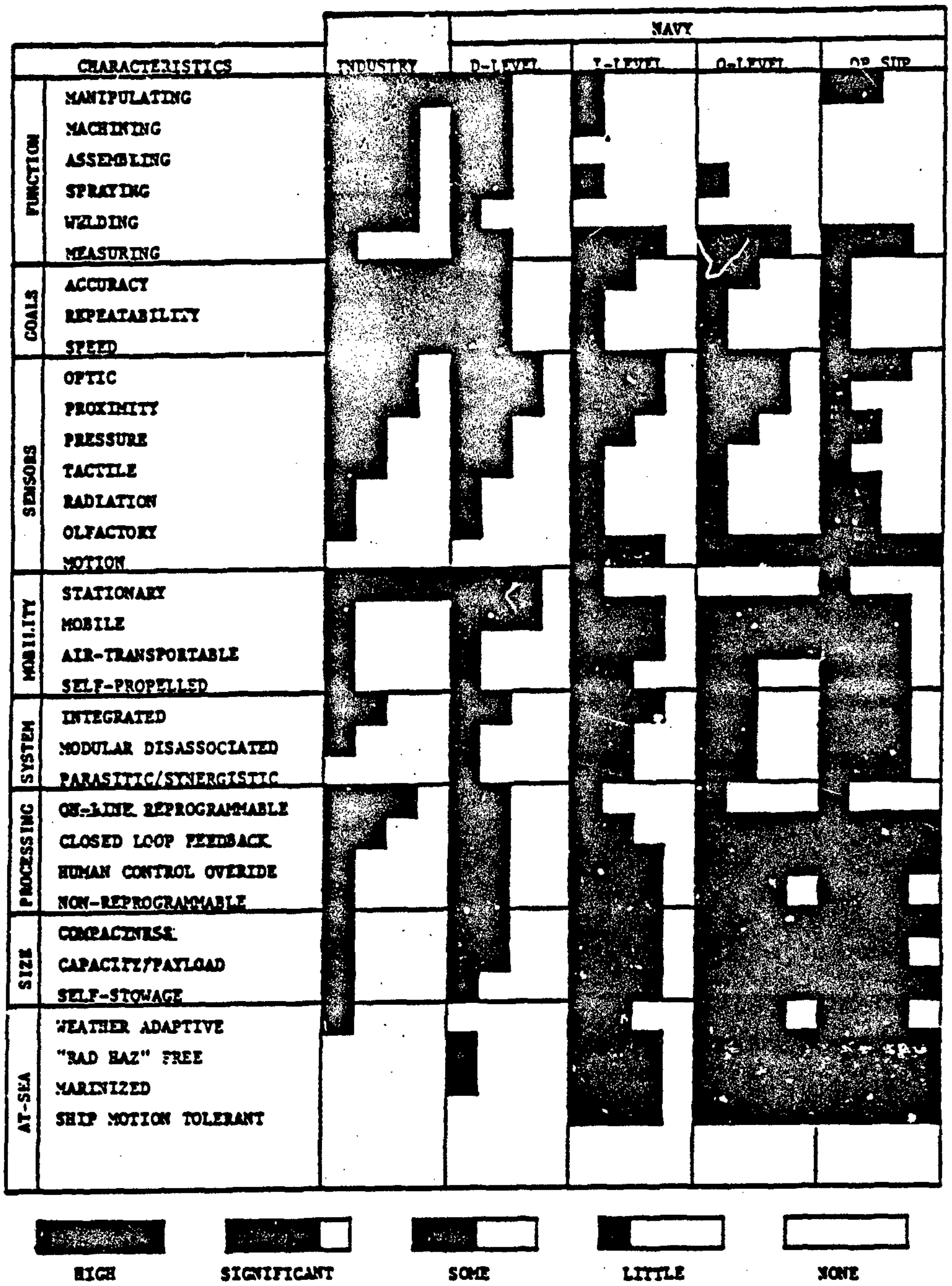


Figure III-I

The basic results of this qualitative assessment are indicative of the specific nature of the divergence of naval aviation's required robotic characteristics from the industrial base-line. Some of the rationale developed by the survey will be addressed in the following discussion of the characteristics shown in Figure III-1.

Function

Here there are generally "significant to high" existing industrial applications, familiar to anyone who sees a television commercial or who reads a news magazine. When considering potential Navy applications, the concensus opinion was that there was "some" existing and potential applicability in the NARF environment for the familiar functions of manipulating, machining, assembling, spraying and measuring (in this case more than industry due to the "Diagnostic" nature of repair) with only a "little" potential for welding. All of the functional characteristics with the exception of "measuring" are considered to have less applicability in the NARF than industry primarily due to the non-repeatable and mobile nature of the NARF work tasks. The common industrial functional characteristics drop off dramatically in potential applicability to "O" and "I" level maintenance and operational support (OP-SUP) tasks. This is primarily due to the non-manufacturing nature of the requirements, as well as the at-sea environment constraints. Again, "measuring" shows significant potential due to the inspection/diagnostic requirements of maintenance. Another notable variation is the rise in potential of "manipulating" to "some" in the OP-SUP area, due to aircraft arming, fueling, moving and land-launch requirements.

Goals

The common robotic characteristic goals of accuracy, repeatability and speed all have high existing applicability in industry. As would be expected from the previous discussions, the industrial environment is reflected to a lesser degree in the D-level environment with "some" potential and existing applicability.

Again, as the environment "goes to sea" in the I and O-levels and OP-SUP, applicability drops to "little" with the exception of "accuracy" which retains at least "some" applicability in aviation maintenance at sea, again related to diagnostics and measuring.

Sensors

Sensory characteristics considered are listed in Figure III-1. The first four, optic, proximity, pressure and tactile are all currently being developed, refined and applied in industry with "some" to "significant" growing use. Naval aviation potential for these characteristics is very nearly that level of applicability existant in industry with some reduction due to maintenance and at-sea variables. The three remaining sensory characteristics, radiation, olfactory and motion, are related primarily to naval aviation needs and have "little" or "no" industrial applicability. The need for motion sensors in at-sea robotic systems (particularly those that are mobile or self-propelled) is obvious. Radiation sensors relate not only to obvious nuclear weapons scenarios, but also to friendly and hostile infra-red and radar and other radiation used in weapons and communications. These could be used to control or communicate with naval robotic systems, or interfer with the systems functions, or are to be sensed and identified as a function of a robotic weapons system. Olfactory (or "particle") sensors would be used to automatically sense toxic or debilitating free gases, either threat generated or inadvertently created by accident or shipboard fire.

Mobility

The treatment of mobility characteristics verifies earlier assertions that industrial requirements generated primarily fixed, stationary robots. There is a "little" industrial applicability for mobile, air-transportable and self-propelled systems (some of which are in service). Again, in verification of previous assertions, those surveyed generated potential "significant" and "high" applicability for mobility characteristics for sea-going robotic systems. Note that mobile systems have more applicability in D-level aviation maintenance than in indus--- due to mobile work station requirements as opposed to fixed production lines. . r transportability has "high" applicability for deploying squadrons (O-level) and "significant" for I-level and OP-SUP since replacement systems would be flown to the deployed carrier. The self-propelled characteristic is really a sub-characteristic of "mobile" but has separate and unique significance on crowded hanger and flight decks, where its incorporation can eliminate the need for a separate tow-tractor in some applications. There is a "little" naval applicability for stationary systems in shore-based I-level maintenance facilities and certain shipboard OP-SUP applications.

System

The survey of system integration characteristics had rather indeterminate but predictable results. As seen in Figure III-1, the concensus was that integrated systems were predominantly applicable to all environments. There was, however, some appreciable navy potential for "modular-disassociated" and "parasitic/synergistic" robotic systems characteristics. Modular-disassociated systems were defined as those wherein the component subsystems are individually self-contained (modular) and interact with each other via signals and stimuli received without physical connection or (disassociated) integration (such as a robotic system with an optical sensor which controls its input stimuli and will respond to a remote laser-designator reflection). A parasitic system is one which would use the energy presence, or propulsive force of a host system, but whose function is totally unrelated to the function of the host system (such as an olfactory smoke/gas sensing device consisting of a large number of integrated sensors mounted in the ship's ventilating system, using the ventilation ducts as a physical location vector grid to locate the source of the smoke/gas). A synergistic system would be similar to the parasitic system but in this case each of the otherwise unrelated systems would benefit from the function of the other (such as an olfactory sensing robotic system carried by an aircraft on an otherwise dedicated mission which senses Biological or Chemical warfare agents and automatically transmits concentration and location, from the aircraft's inertial navigation system, and simultaneously seals the cockpit and puts the crew on 100% oxygen).

Processing

For the majority of industrial robotic applications, the integral data processing is reprogrammable and in most cases, on-line reprogrammable. There is also "some" industrial applicability for closed-loop-feedback self-correcting systems, and "little" use of human control override (stand-by safety operator) or non-reprogrammable (single purpose/special purpose) processing and control. As in the case of most other characteristics, the NARF, or D-level of aviation maintenance, again reflects industry, but again at a lower level of potential applicability except for human control and non-reprogrammable system which are more applicable to the maintenance rework environment due primarily to mobile work stations and case-basis tasks respectively. In the at-sea I and O-level maintenance and OP-SUP environments, there is "little" potential for on-line reprogrammable applications, which imply that the same system will significantly change function from day-to-day or week-to-week. Closed-loop-feedback and human control override characteristics attain "significant" to "high" applicability in I and O-level and OP-SUP due to the hazardous (flight deck/hangar deck) environment and proximity and involvement of fuel, weapons and personnel. Non-reprogrammable characteristics will have significant applicability at sea, where systems will tend to be small, mobile and single purpose.

Size

The fact that compactness, high capacity and self-stowage are highly desirable characteristics for the crowded and hazardous at sea environment, and have "little" applicability in industrial robotics should come as no surprise. These size related characteristics have more applicability in D-level maintenance than in industry due to the mobility characteristics desirable in a NARF with its moving work stations and case-basis tasks.

At-Sea

Very little needs to be said about the obvious applicability of these characteristics. The only mild surprise came from industrial respondents indicating that there was some potential for weather-adaptive characteristics in industrial systems, primarily related to that small percentage that were judged "mobile" and/or "air-transportable" and hence potentially subject to elemental exposure.

From the responses a further mathematical extrapolation produced Figures III-2 and III-3.

Figure III-2 prioritized industrial characteristics from 100% to 1%. Figure III-3 utilized the industry based prioritization structure of Figure III-2, however, naval values differed substantially. Naval characteristics were sub-divided into four separate categories each representing 25% of total potential navy application. These areas were further sub-divided in four equal units each representing 6.25% effectively normalizing the continued navy applications potential.

Figure III-4 was arrived at by combining the Industrial and Naval Aviation potential applications levels from Figures III-2 and III-3. In Figure III-4, the Industrial level of potential application is graphically subtracted from the Naval Aviation level of potential application. The resulting chart is in effect, a normalized graphic indicator of characteristics of robotic systems

ASSESSMENT OF EXISTING AND

FUTURE INDUSTRIAL APPLICATIONS

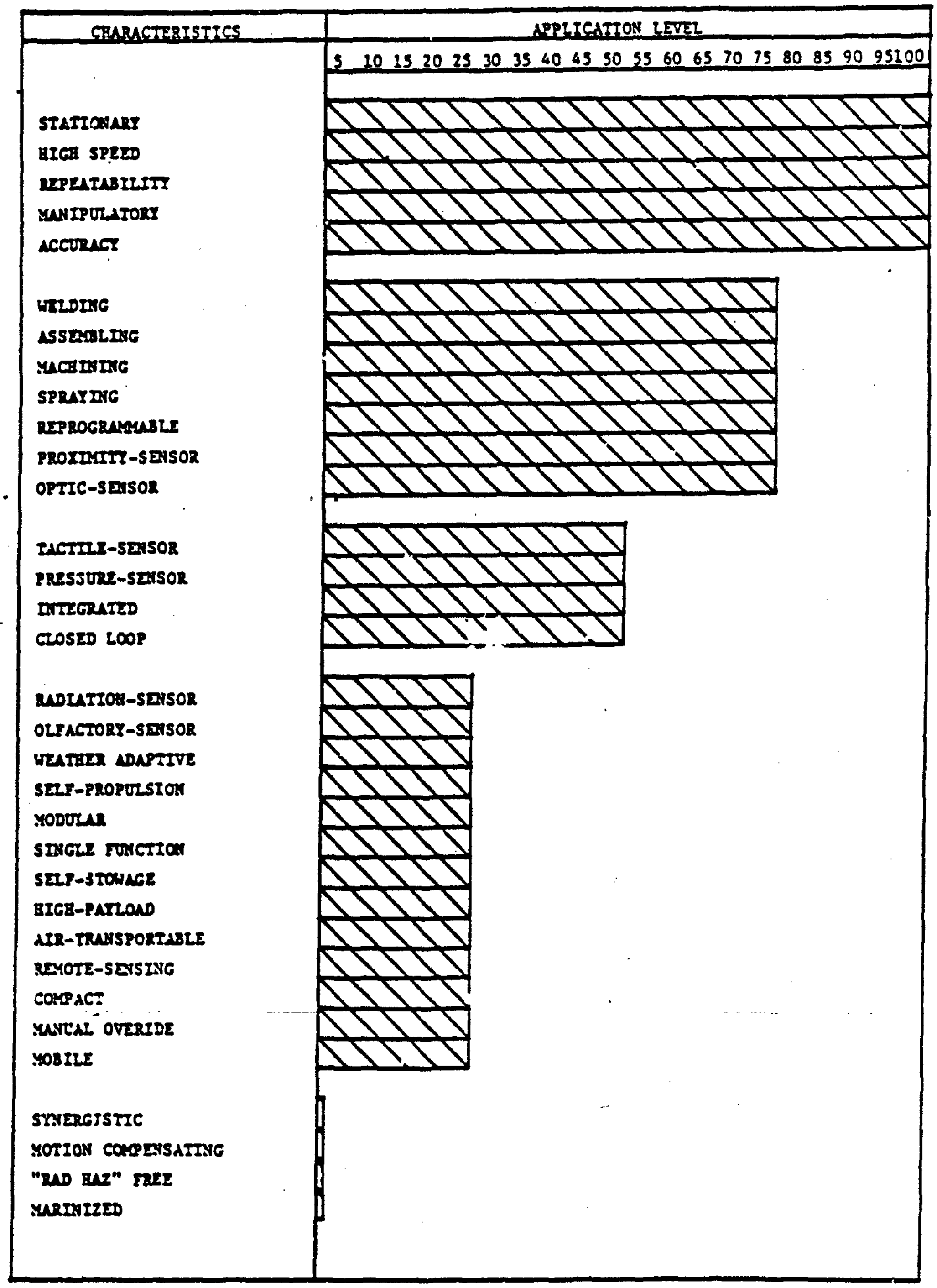


Figure III-2

ASSESSMENT OF OVERALL

NAVAL AVIATION POTENTIAL APPLICATIONS

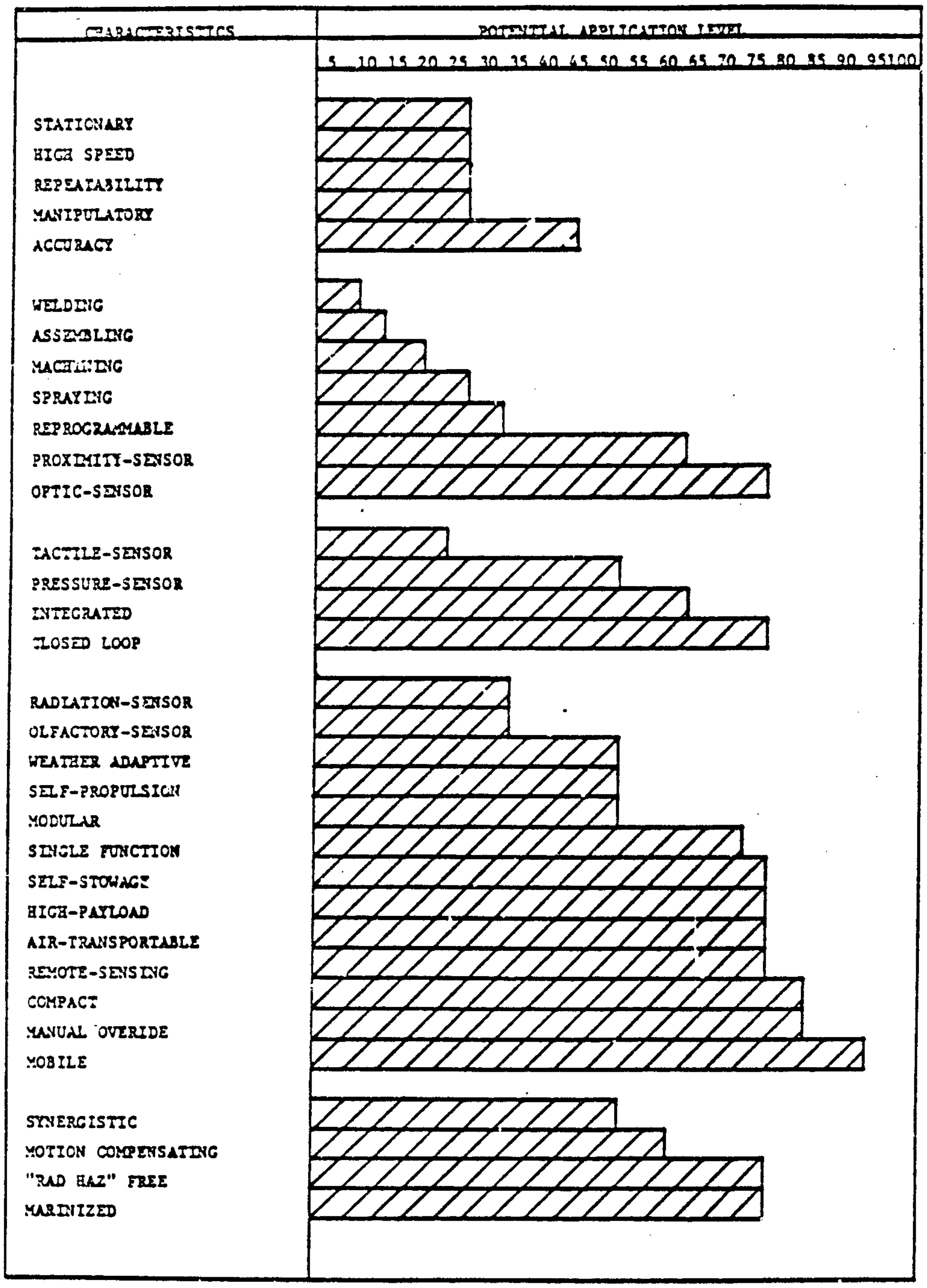


Figure III-3

ASSESSMENT OF OVERALL
NAVAL AVIATION POTENTIAL APPLICATIONS CHARACTERISTICS

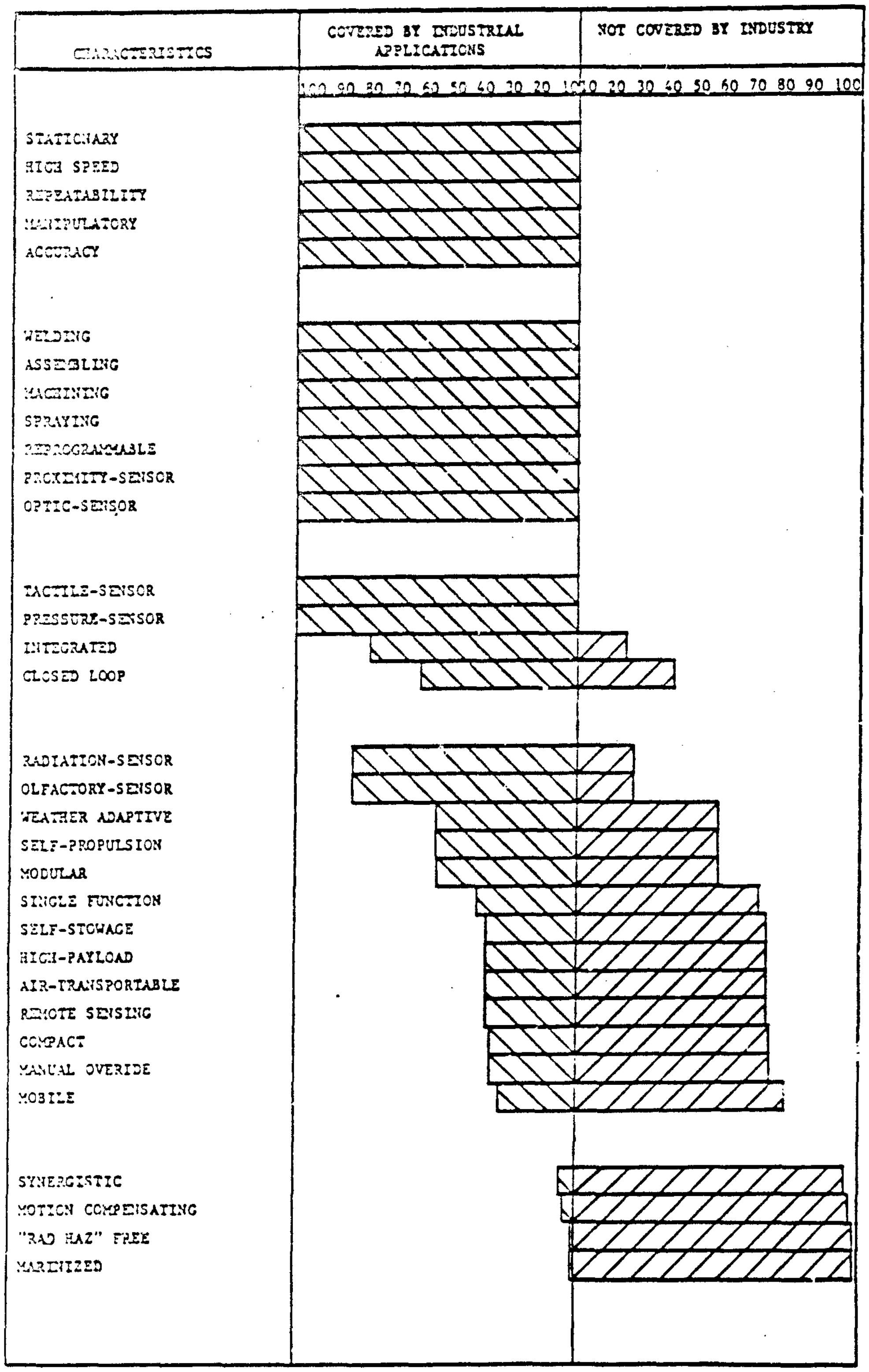


Figure III-4

judged necessary for potential naval aviation applications which will have no comparable level of application in industry. The right hand column of Figure III-4 labeled "not-covered by industry" represents the robotic characteristics necessary to naval application that qualitative analysis indicates must be developed by the Navy due to a lack of applicability, and hence interest, in industry.

The graphic results just presented illustrate the major findings of the applications survey of this effort, namely:

- Few of the characteristics required of current industrial robots have any great degree of applicability in potential Navy, or naval aviation, robotic functions.

- Conversely, the potential application of robotic systems to naval aviation functions generates a set of characteristics for these systems not currently incorporated in industrial applications.

The set of "Navy-unique" characteristics can be logically grouped into three broad categories as follows:

- minimum size
  - compact design
  - air-transportability
  - high weight capacity
  - self-stowability

- maximum flexibility
  - inter-system synergism
  - general mobility
  - remote sensing ability
  - single function design
  - adaptive modularity

- shipboard adaptability
  - marine environment tolerance
  - motion compensation capability
  - "Rad Haz" free design
  - self-propulsion capability
  - manual override controllability

These Navy-unique characteristics imply that a "Navy-robot" might in fact be considerably different than its industrial counterpart. The survey which generated these results provided a considerable amount of attitudinal and philosophical insights into the applicability of robots to naval aviation tasks.

Chapter IV

## A "Robotics" Concept for Naval Aviation

### A. Definition and Purpose

As noted earlier in this report, the Robotics Institute of America defines a robot as "a reprogrammable, multifunctional manipulator designed to move material, parts, tools, or specialized devices through variable programmed motions for the performance of a variety of tasks". The applications survey and its results show that for naval aviation purposes, this definition is much too specifically oriented to industrial applications and is conceptually very shallow, in that it merely describes "what" a robot is. To accomplish the purpose of this effort, it was necessary to examine not merely the "what" of robotics but also the "how" and "why", i.e. the uniqueness of Navy applications requires that the conceptual purpose of robotics technology be addressed. If one examines robotic development objectively, and discounts the sensitivities of organized labor, it is clear that the basic purpose of all robotic systems is to increase efficiency and/or productivity by either enhancing or eliminating the human worker.

Considering this basic purpose, and moving out of the industrial assembly-line environment to the broad scope of naval aviation operations and support, we may establish a basic robotics concept (or philosophy), stated as follows;

"The purpose of robotics technology is to either enhance, reduce or eliminate the human presence or transfer-function by using multifunctional programmable systems to automatically translate input stimuli into logically determined actions or signals".

This concept is highly applicable to naval aviation needs in that it addresses the potential enhancement or replacement of all human transfer functions, including the kinetic (manipulation and motion), logic (decision) and sensory. It also allows robotic systems to be mobile, transportable, self-propelled, or conversely, totally static with a logic or sensory function. The systems may be modular and widely disbursed or "parasitic" and totally dependent on a host system. In short, using this broadened concept, Navy-unique characteristics may be accommodated. Furthermore, applications may be imaginatively concieved that will improve overall operational effectiveness (and hence by definition "Navy productivity") through:

- Safety
  - by reducing human exposure to hazardous environments
  - by reducing "human error" potential in the performance of hazardous functions
  - by reducing or eliminating human response lag to catastrophic events
- Response Capability
  - by reducing equipment "down-time" for maintenance
  - by reducing human decision time requirements
- Manpower
  - by reducing overall manpower requirements
  - by increasing existing manpower effectiveness
  - by reducing skill/experience level requirements
  - by reducing training requirements

## B. Attitudes and Semantics

As might be implied from the previous section, and this report in general, "robotics" and "robot" are at best ill-defined terms at present. The general perception of the impact and scope of robotic technology is widely diverse, even among the technically knowledgeable. Much of the present problem is due to the fact that senior managers in both the public and private sectors have come to associate Japanese industrial productivity and efficiency with wide use of robotics. The desire to attain those same levels of productivity has resulted in widespread top-down direction to "do something with robotics". Generally, the senior manager providing this direction has little or no idea as to "what" should be done with "robotics", or "how" to do it, or for that matter what robotics really are. The result is generally an adverse reaction by middle and lower management to the mention of robotics, and a reluctance to attempt anything more than a direct technology transfer. Within DOD in general, and the Navy in particular, there have been several initiatives directed towards the implementation of various robotic applications in the in-house production facilities (NARFs). When labeled as "robotic" applications, these efforts have met with varying degrees of success. On the other hand, a relatively large number of applications of technology that fits the "Robotic Concept" of the previous section have been implemented in NARF's and other industrial activities over the last twenty years, and have generally been highly successful. Some examples are;

- on-line programmable, six-axis, numerically controlled milling machines - have wide application throughout the NARF's along with earlier tape and disc programmable models, and have been highly successful in increasing productivity for some twenty years.
- GATS - Gyro Automatic Test System - used in several NARF's to test and calibrate gyro-instruments - these systems usually decrease manhour investment by a factor of ten with dramatic improvement in quality and precision.
- DITMCO - trade name for a programmable, digital, electrical continuity and condition test computer, which is umbilically connected into the aircraft wiring system and is programmed to automatically test and record the condition of all circuits - reducing manpower investment by a factor of 100 from the previous method of pole-to-pole manual continuity check. This system is very significant in human error reduction in dealing with the miles of wiring involved.
- numerically controlled altimeter test unit - combines a vacuum chamber, wide angle lens camera and a pre-programmed "altitude" schedule to reduce overall time involved in altimeter test by a factor of 16, and human man-hours by a factor of 40.

These systems, and many others in day-to-day use in NARF's and AIMD's have a few characteristics in common;

- all are user designed or modified
- none fit the RIA definition of a "robot"
- none were ever referred to as "robots" or purchased under a "robotics" implementation program
- all adhere to the "Robotic Concept"

In general, the lesson of robotics, to improve productivity by enhancing or eliminating the human presence, has been well applied in the Navy's industrial segment. There remains a strong resistance to the direct transferral of "robotic systems" from private industry to NARF's which seems to be attitudinal in nature. This resistance to "robots" in the workplace by workers and middle management has been investigated by sociologists and industrial psychologists. It has been found that a certain portion of this resistance is due to organized labor's long opposition to automation in any form. However, in many instances such as in the NARF's, "advanced automation" concepts have been readily accepted while "robots" have been actively opposed. One researcher has labeled this reaction the "Star Wars Syndrome" arising from the simultaneous overexposure of "robots" in both popular entertainment (R2D2) and in serious economic analysis (Nissan vs Chrysler etc.). The general public receives simultaneous pictures of "robots" as comic relief in deep space, and as miraculous economy-saving devices which have allowed "foreigners" to disrupt the "American-way-of life". The overall result is general skepticism and a marked lack of public credibility for robotics as a serious technology. This attitude was strongly present during interviews with current and former fleet aviation maintenance and operations personnel. The initiation of a discussion of "robotics applications to naval aviation operations and support" usually resulted in reactions ranging from passive skepticism to open verbal hostility. When the concept was introduced as "advanced support technologies", and that NAVAIR personnel were said to be willing to invest research and technology assets to help the fleet operate and support its increasingly complex "advanced technology" weapons systems - it was received with high enthusiasm and total cooperation.

Due to the limited transferability of traditional industrial robotic technology to naval aviation applications, it is strongly recommended that the highly transferable "Robotic Concept" be adopted as the fundamental philosophy for an "Advanced Support Technologies/Robotics" (ASTR) Program.

Adoption of the ASTR semantics helps to eliminate another problem associated with attitudes and definitions. Under the broadened "Robotic Concept" virtually any automated, computerized or remotely controlled system may be said to be "robotic". The establishment of a thus-defined "Robotics" Program would then imply that many mature, existing programs would be candidates for annexation. This, of course, would be highly inappropriate, particularly in the case of a number of current and emergent weapons systems. The use of "Advanced Support Technologies" alleviates this potential conflict since "robotic" combat (non-support) weapons systems have their own well established programs. For example, airborne robotic combat systems are either "guided missiles" or "RPVs" torpedoes and mines are sub-surface robotic combat systems etc. In fact, there are a significant number of weapons and weapons support systems that have been in U.S. and foreign naval usage for sometime, and which fall under the definition of the "Robotic Concept".

## Naval Robotic Systems

### A. "Robotic" Systems in Current Use

As stated in Chapter IV, there are a number of systems in current naval usage that qualify as "robotic" in nature both under the Robotics Institute of America (RIA) definition and as defined by the "Robotic Concept" for naval applications, put forth in this report. Consider several familiar systems which are examples of the applied "Robotic Concept" although none of these systems has ever been labeled as, or considered to be, a "robot".

#### 1. Cable-controlled Underwater Remote Vehicle (CURV)

The first CURV unit was built and tested by the U.S. Navy in the early 1960s. As originally produced the CURV unit was intended to recover bottomed torpedoes. The CURV-III successfully recovered an H-bomb lost off the coast of Palomares, Spain in 1966 and rescued two individuals trapped in a submersible 1500 feet below the surface on 1 September 1973. The CURV is a cable controlled and operated vehicle with the human controller operating the vehicle from a remote site above the ocean floor. The CURV fulfills all requirements set forth in the "Robotic Concept."

#### 2. Automatic Missile Loader/Launcher (AMLL)

The automatic loader/launcher systems incorporated on the TARTAR (RIM-24), TERRIER (RIM-2) and the STANDARD MISSILE 1 and 2 (RIM-66, RIM-66B and RIM-67) are robotic units manipulating specialized devices for the performance of a task. These units automatically transport missiles weighing up to 2,900 lbs. (RIM-67) from the barbette structure on to the launch platform. In so doing, they augment/reduce or eliminate the human transfer function or presence, thereby fulfill requirements contained within the "Robotic Concept."

3. Automatic Naval Gun Mount (MK 45/MOD 1) (ANGM)

The MK 45/MOD 1 is capable of automatically loading and firing a mixed magazine load of both five inch (127 mm) conventional rounds and guided projectiles. Rounds are automatically transported from the magazine to the gun where an automatic loader places the round in the chamber and prepares for firing. A computer will automatically aim the MK 45/MOD 1 at the appropriate target. This simple transporter/loader system could be considered to be robotic in nature under both the RIA definition and the generalized naval robotic concept. Under the RIA definition the unit manipulates material or specialized devices through programmed motions for the performance of a task. It also eliminates the need for a human transporter/loader, fulfilling requirements for the "Robotic Concept."

4. Phoenix (AIM-54C)

The Phoenix air intercept missile (AIM-54C) is integrated with the AWG-9 radar/fire control system located on board the F-14 Tomcat. The AWG-9 radar/fire control system maintains the capability to track-while-scan 24 separate targets and simultaneously direct six AIM-54C's to their respective targets. A synergistic relationship is thus created between missile and aircraft. The AIM-54C relies on semi-active radar homing during the cruise phase of the flight. During the actual attack, active terminal radar homing augmented by artificial intelligence takes over. The inclusion of artificial intelligence in both the AWG-9 and the AIM-54C removes the need for a human to direct missiles to target. Thus, the system meets the parameters for it to be considered robotic in nature via the "Robotic Concept."

5. Close In Weapons Systems (CIWS)

In 1967 the Israeli destroyer EILATH was sunk by a sea skimmer fired from an Eygptian fast patrol boat. In 1971 an Indian Navy fast partol boat of the "Osa" class engaged and severely crippled several Pakistani warships utilizing surface-to-surface missiles. These two examples pointedly indicated the need for automatic close in weapons systems (CIWS) which could engage, divert and/or destroy incoming anti-ship missiles flying at or below 100 feet and closing at speeds of up to 700 miles per hour. The "human transfer function" was not up to the task.

To counter this threat, the United States Navy has developed the Vulcan Phalanx (20 mm/76 cal MK 15) Gatling gun for use against high speed anti-ship missiles. The system is capable of firing 3000 rounds per minute of 12.75 mm saboted depleted uranium projectiles. The Vulcan Phalanx is integrated with the ship's main search radars providing for a synergistic relationship between gun and ship. Upon identification of a target maintaining characteristics similar to those stored in the Phalanx memory (as typical of an anti-ship missile), the Phalanx will automatically acquire, track and evaluate the threat. Once identified as a threat, the Phalanx will correlate radar echoes and plot the target's course. Artificial intelligence will allow the system to select the most dangerous target in a multiple threat environment while maintaining continuous track on other targets. The system will calculate the optimal moment for opening fire, engage the target and control fire action. Firing parameters are corrected automatically via correlation of actual projectile trajectory, theoretical trajectory and target's anticipated course. Upon destruction of the initial target, the system will engage the next most dangerous target or return to "on-alarm" position. The system operates devoid of human participation and can engage divert and/or destroy incoming anti-ship missiles in a matter of seconds. This system utilizes a high degree of artificial intelligence but would not be defined as robotic under the RIA definition. Classification of this system as robotic in nature is allowed under the "Robotic Concept."

6. Dagaie Decoy (Squid)

The Dagaie decoy system, was developed by the French Navy, and utilizes a high degree of artificial intelligence to detect and decoy high-speed incoming anti-ship missiles. A synergistic relationship between the ship and Dagaie is, again, required via integration of the ship's main search radars and the Dagaie unit. This system is not in use on United States Naval Vessels.

The Dagaie system utilizes external parameters (ship's course, speed, wind velocity/direction and the azimuth or bearing of the threat) supplied by the ship's main computers to generate an effective decoy. Upon detection of an anti-ship missile, the Dagaie can place chaff and flare decoys in position within three seconds. The decoy's effective duration is thirty seconds for IR (Infrared) and five minutes for ER (Electromagnatic Radiation), allowing it to divert more than one missile at a time. Artificial intelligence contained within the launcher will allow enplacement of a decoy (covering several radar frequencies) with appropriate dimensions and maximum radar cross section. The IR decoy (colocated with ER decoy to provide maximum effect) has a high energetic brilliancy over the entire IR bandwidth at a credible height.

This system can operate manually or, again, devoid of human participation. The degree of artificial intelligence is comparable to that of the U.S. Vulcan Phalanx. The system is considered robotic under parameters set forth in the "Robotic Concept."

Examples of systems which are robotic in nature are extensive and do not merit further discussion. These samples do, however, indicate that the United States Navy (as well as other Navies) routinely develop, deploy and maintain weapons systems which "seek to augment/reduce or eliminate the human transfer function or presence by using multi-functional programmable systems to translate input stimuli into logically determined signals or actions". These systems, utilizing degrees of artificial intelligence, are robotic in nature but cannot be classified as such under the RIA definition.

B. Guidelines For Advanced Support Technologies/Robotics (ASTR) Systems

One of the major tasks of this effort was to recommend "rational" applications of robotics to naval aviation operations and support. During the early stages of the assessment "operational" or "combat" robotic applications were addressed. As was discussed in Chapter IV, it soon became apparent that many "Robotic Concept" combat systems were either in service or under development, but could never be included under the umbrella of a "robotics" program. This left the largely virgin area of operational support, with the major exception of the naval aviation depot-level maintenance system (NARF's) which, it was discovered, had been long time subscribers to the "Robotic Concept." The remaining area of at-sea maintenance and operational support (and any other non-weapon systems) applications is therefore available for exploitation under the semantically safe title of "Advanced Support Technologies/Robotics" or ASTR applications. The basic specifications or characteristics for ASTR systems were defined as follows:

- required that the system or application be:
  - incapable of endangering friendly forces
  - safely operable in required sea states (actual sea state will vary with the application)
  - tolerant to the marine environment
  - non "Rad Haz" generating
  - compatable with all applicable specifications
- desired that the system or application:
  - require minimal special training
  - require minimal special support
  - generate minimal interference with standard operations
  - be air-transportable (as a system or in subsystems)
  - have fault-tolerant design
  - have fail-safe design

Once these basic considerations had been established, various potential applications of the "Robotic Concept" as ASTR systems were explored - and since that within the above characteristics, only imagination limited the scope of potential applications - it was necessary to establish classifications in terms of technical and developmental risk and operational and logistic impact on host systems and existing operations. Semantically lumping risk and impact, the following classes of potential ASTR applications and systems were defined:

- <u>low impact/risk</u>
  - combination of existing systems
  - no modification required to host system/platform
  - no special or unique support requirements
- <u>low to moderate impact/risk</u>
  - current technology - all new system
  - no significant modification to host system
  - minimal unique support requirements
- <u>moderate to high impact/risk</u>
  - state-of-the-art-"plus" technology or systems
  - major modifications to host system required
  - unique support requirements
- <u>high to very high impact/risk</u>
  - advanced technology and/or systems
  - applicable to new design host systems only
  - new and unique support requirements

These classifications allowed a certain practical hierarchy to be establish in addressing the long list of potential applications which ranged from the patently obvious to the truly exotic.

## C. Examples of Potential Naval Aviation Robotics (ASTR) Applications

### 1. Background

The following are potential applications concepts in order of ascending impact/risk. These concepts were selected from a long list of suggested applications and developed in a qualitative, but detailed, manner to the point where they may be said to be practical and ultimately implementable, and should be considered as practical examples of some of the many applications that could be generated from the "Robotic Concept" and/or ASTR.

2. Automatic Selective Jammer

The Automatic Selective Jammer concept is an example of a low risk and low impact application of ASTR, in that it utilizes existing systems and operational modes in a largely non-interfering manner.

This application arises from the need to deter Soviet Naval Aviation (SNA) missile bombers from launching their cruise missiles in sufficient numbers to saturate the Carrier Battle Group's (CVBG) multi-layered defenses. The basic air defense strategy in this case is to jam all threat radars to delay missile launch long enough to have the opportunity to destroy the missile bomber prior to launch. In all senarios for this type action there is high probability that at least one enemy bomber will successfully launch missiles that will penetrate all defensive layers. This potentially successfuly penetration is predicted to be primarily due to delays in the human logic/decision transfer function and the shear complexity of the CVBG/SNA air battle scenario.

A robotic system, composed of the AEGIS air battle control system sensors and computers (themselves robotic systems) the Vertical Launch System (VLS) installed on the AEGIS CG-47 or other escort, a surface launched cruise missile air frame (Tomahawk/SLCM) and a broad band short range jamming payload - could be combined to automatically eliminate the "most probably penetrator" (m.p.p.) as a threat.

The AEGIS system computers, by processing the data-linked inputs from all friendly sensors, would determine early in the battle which of the SNA aircraft was the most likely to penetrate the defenses, based on friendly and threat deployments, actions and predicted actions. Once a "most probable penetrator" was identified, the AEGIS system would automatically launch the SLCM jammer from the VLS. The SLCM would be programmed directly by AEGIS to home on the "m.p.p." and commence jamming while "flying wing" on the SNA bomber using its (SLCM's) own sensors. The jamming would delay missile launch until AEGIS could direct and/or launch air defense assets to eliminate the "m.p.p.". The SLCM jammer could then, or at anytime, be redirected to the next "m.p.p." and delay its launch until elimination.

While this may seem to be a rather frivolous use of the AEGIS and SLCM (after all, the SLCM, with a warhead, could destroy the m.p.p.), it does demonstrate how the "Robotic Concept" of eliminating the human transfer function can be applied to use near-term and existing systems to solve a seemingly insoluble problem arising, in this case from situational complexity and human "decision time" lag. Using the SLCM in a robotic, totally automatic killing mode would violate the "endangering own forces"guideline. There is some logic to using the SLCM as an automatic jammer, since with its endurance and in-flight reprogrammable guidance system it can be used repeatedly and automatically, throughout the engagement while the "killing" is done by Phoenix and SM-2 directed by AEGIS. Overall this concept serves more as a dramatic example of what might be done using the "Robotic Concept", rather than a serious proposal.

3. Robotic Weapons Transporter and Loader

The Robotic Weapons (or "stores") Transporter and Loader concept is an example of a low to moderate impact and risk application in that it uses current, state-of-the-art technology in a new system and application. It does not require any modification to the host system, the aircraft carrier (CV(N)) on which it operates and should have minimal support requirements.

This concept is intended to increase overall operational effectiveness and safety by eliminating the majority of human involvement and equipment interfaces current by required to move a weapon or store from its assembly area to its operational position, mounted on the aircraft wing and/or rack.

The Robotic Weapons Transporter and Loader would be operated and monitored by a single armament technician. This individual would direct its motion and initiate its functions, such as positioning, lifting and loading by means of a hand held controller (pig-tail) attached to the system by electrical umbilical and operated as the director-monitor walks or stands alongside the Transporter/ Loader. The system itself would:

- be self-propelled by state-of-the-art battery;
- have fully castered wheels or rollers for omni-directional planar motion;
- have a gyro-motion sensor that would activate brakes and/or mechanical stabilizers when ship motion limits are exceeded during movement or loading;
- have a mechanical-hydraulic load-lifting system for weapon/store mounting;
- have a electro-optical, or laser, or cable-bell-mouth positioning system to assure accurate weapons lug to rack positioning during loading (also motion compensating);
- have positive locking cradle for weapons carriage, making dropping of load impossible; and
- have a "dead-man" switch on the controller.

This system could be designed and built now. It would eliminate all but one human monitor-director from the now complex ordinance transfer and loading process, greatly reducing human-error potential. The motion sensing and compensating system would virtually eliminate the possibility of a dropped or run-a-way weapon. The positive locking feature coupled with automatic weapon-to-rack positioning would greatly reduce loading time. Castering wheels with automatic braking when motion limits are exceeded would allow rapid and flexible movement in the flight deck environment.

The Robotic Weapons Transporter and Loader is considered to be a very practical and implementable concept, wherein the application of the "Robotic Concept" might significantly enhance carrier operations and safety for a relatively small investment of resources.

4. Automatic Flight Deck Fire Sensing-Analysis-Suppression System (F-SAS)

The F-SAS concept is classified as a moderate-to-high impact and risk application of robotics, due primarily to the fact that it would require significant modification to, and integration with the host system. The purpose of the system is fairly self-evident in its nomenclature, it would automatically and rapidly sense, analyse and precisely apply the proper suppressant to a flight-deck fire, eliminating the time lag due to human indecision and access, reducing significantly the probability of catastrophic results recently common to this type of fire. The system would also, through early and automatic application of the proper suppressant reduce the hazard to human firefighters and other personnel in close proximity, and allow hand-held systems to be applied for final extinguishing. The F-SAS system would be composed of the following elements and interactions;

- optical sensors mounted on the fore and aft upper inboard portions of the island structure, and/or on masts fore and aft of the island (similar to aft mast on CV-66, CV-67, and CVN-68), to initially sense the fire, coupled to
- spectographic analysers which would determine the type of fire, and
- a computer programmed flight deck geographic grid locator which would provide the precise location of the fire and provide it to
- the processing subsystem which also would continuously receive ship motion and wind-over-the-deck data from ship's sensors, integrate them with the location and activate
- suppressant nozzles (co-located with the optical sensors) whose overall trajectory is set by the location, motion and wind inputs, and whose supply of suppressant is provide from a multiple suppressant manifold controlled by the spectrometer output (i.e., the kind of fire), and
- one or several of the four (or more) nozzles will apply a stream of the proper suppressant precisely on the fire a fraction of a second after it is initially "observed" by the electro-optical sensor.

This system is entirely feasible with only minor extension of today's technology, plus some ship modification. It could be left in the "on" position constantly since optical/spectographic sensing could screen out all "acceptable" fires such as jet exhaust, flares and deck lighting.

This is an example of a modularly associated, symbiotic robotic system whose function is primarily in sensory and logic modes in the process of sensing, locating and analyzing the fire, and is manipulatory (in the traditional robotic sense) only in applying the suppressant.

5. <u>Below-Decks Fire Sensor-Analyser-Locator System (F-SAL)</u>

Although the F-SAL concept lies outside the specific technical province of NAVAIR, it is included in this report as an example of a system which adheres to the "Robotic Concept" and the ASTR definition, but functions in a totally non-kinetic mode, using only sensors and logic. The F-SAL is considered a moderate-to-high risk and impact application due to extensive shipboard installation requirements.

This system would consist of only three elements;

- an extensive system of concentration sensitive (particle counting) smoke sensors (or sniffers) installed in the ship's ventilation ducts
- an independent system of flow sensors (direction and velocity) installed in the ship's ventilation ducts
- a computer logic and display system receiving data from both sniffer and flow sensor systems and applying it to the ventilator system geometry.

The function is almost self-explanatory. Given the known fact that the presence of smoke in a ship's compartment is more often than not an indication that there's a fire - somewhere - not necessarily in that compartment, but is present as a result of the action of the complex ventilation system. Given the known geometry of the ventilation system, the velocity and direction of flow (which will vary with the number of vents open or closed, and blowers on or off) at key locations in the system and the location and concentration of smoke or fumes, computer logic applied to vector analysis will provide the most probable location(s) of undetected or hidden fires to damage control personnel. The fire location and alarm would be provided simultaneously on an electronic display board in Damage Control Central.

This system would eliminate the ambiquities and delays inherent in locating fires aboard large ships, reduce false alarms, and needless fire drills and generally increase safety and operational effectiveness.

6. Automated Hangar-Deck Service System

This concept, while not highly sophisticated, must be classified as both high risk and high impact, since the subsystems required would exceed current state-of-the-art design, and the general application could only be incorporated as an integral design feature of new construction carriers.

As envisioned, this application would result in a hangar deck wherein virtually all services and major tool functions are suspended from, and move on, an overhead grid-track system, under rail conductor supplied ("street-car") electrical power. Specific services, such as electrical supply, hydraulic pressure source, pneumatic source, etc. would be "requested" electronically by hand-held, push-button, coded transmitter. Computer logic would direct the requested service module to the proper location on a first-come-first-serve priority and via the most direct non-interfering grid path. It seems logical that the overhead grid-track/conductor/support system would have to be integrally incorporated into the flight deck support (hangar deck overhead) structure. Several designs for this system have been conceived, but are far too complex, and at this point far to embryonic to discuss in this report (hence high risk). Suffice it to say that initial efforts have determined that this system is entirely feasible and implementable, but with attendant high risk and high impact.

The result of this application would be the elimination of much of the support equipment from the hangar deck work floor, and the minimization of aircraft and equipment movements for servicing. This should ultimately improve operational effectiveness by reducing "down time" for maintenance by maximize support equipment availability and reducing hangar deck traffic.

D. Summary

It should be emphasized that these concepts have been put forth as examples of the applications of the "Robotic Concept" to naval aviation operations and support, and not as recommendations resulting from the overall assessment. Rather than pointing toward specific applications, the current assessment has very convincingly demonstrated that there is much to be gained from systematically applying the "Robotic Concept" of enhancing and/or eliminating the human transfer function to the solution of naval aviation problems. This is particularly true in the at-sea maintenance and support arena, hence the use of "Advanced Support Technology/Robotics" (ASTR) as a recommended program title.

## Chapter VI

### NAVAIR Implementation of the Robotics Concept

#### A. Advanced Support Technology/Robotics (ASTR)

As has been made abundantly clear, the current assessment has resulted in the determination that NAVAIR should consider the implementation of the "Robotic Concept" in the development of advanced support technologies on an organized programmatic basis via an "ASTR" Program. It is suggested that this program should at least in part be patterned after the traditional exploratory development of operational weapons systems.

New operational systems generally emerge from the research environment in one of two ways; in a deliberate, evolutionary manner, drawing on the resources of a well established "technology base"; - or dramatically and quickly, born fully mature as a result of a successful "technology demonstration" program. Both are proven and well accepted methods for advanced systems development and technology exploitation, and are highly appropriate to the suggested ASTR program.

In general ASTR requirements will either be extremely obvious and logical, or obscured by procedures and systems which have changed little over the last three decades. There are several "robotic" type systems now or previously in service which demonstrate this requirements concept. The Vulcan-Phalanx CIWS is an example of a fully automated system brought to early maturity by technology demonstrators in response to the obvious and urgent requirements of cruise missile defense. The less successful VAST system is an example of an ASTR type concept developed from the existing technology base of the day, as a result of "hidden" maintenance support requirements for avionics revealed by analyses of the then new 3-M data base.

An ASTR program might therefore be composed of two major elements;

- <u>ASTR Technology Base Program</u> that portion of an ASTR Program that would <u>search</u> for requirements using all the presently available data bases as its sources for a unique requirements, or applications identification system, coupled with a technology identification system and finally a technology assessment process, all of which when functional will identify requirements and "investment" technologies for technology base inclusion predicated on overall generic benefit to the fleet in terms of increased effectiveness, increased safety or increased efficiency of operation.

- <u>ASTR Technology Demonstration Program</u> - that portion of an ASTR Program that would <u>respond</u> to urgent, obvious or directly imposed requirements by applying mature or state-of-the-art technologies to a definitive technology demonstrator development process with delineated milestones and procedures optimized for the expeditious and successful development of an advanced technology system ready for pre-production prototyping.

Figure VII-1 illustrates a suggested functional process for an ASTR program combining these two elements.

The primary emphasis in the suggested Technology Base development process is placed on the total exploitation of both the available ADP data base and the little used, but highly valuable "experiential data base", i.e., the "corporate memory" of fleet operators, fleet and civil service maintenance personnel, and the test and evaluation community. Systematic processing of the information contained in these disparate data bases must result in the extraction of potential ASTR applications. "Expert" analysis of the applications would in turn result in the identification of required technologies, which, when properly aggragated and statistically assessed, would provide a hierarchy of high pay-off "investment" technologies for subsequent development and inclusion in the data base.

The major thrust of the suggested Technology Demonstrator Program development is to establish a concept demonstrator development process, by which near-term ASTR applications may be pursued from concept definition through preliminary conceptual design and proof of principle. This could be followed eventually by demonstration via a well-established systems engineering approach ensuring a low-risk, high-quality output. Such an effort would include integrating state-of-the-art technologies into a full-scale technology demonstrator system resulting in early proof of concept and development decisions.

Chapter VII

## Conclusions and Recommendations

### A. Conclusions

The following is a summary of the major conclusions of this assessment:

1. Few, if any present industrial robotic systems are directly applicable to naval aviation needs, particularly in the at-sea environment

2. Significant adverse reaction to and misunderstanding of, the term "robot" exist within the fleet and "blue collar" civil service

3. Evaluation of robotic applications results in the recognition of a basic robotic concept - the elimination and/or enhancement of the "human transfer function" or presence in applications that are manpower-intensive, dangerous or inhospitable to the human presence, or otherwise basically inefficient due to human limitations

4. There is high potential for the robotic concept (above) to improve naval aviation manpower application and efficiency as well as overall operational effectiveness

5. The robotic concept has been and is being well applied within the NARF's as a result of both internal and NAVAIR initiatives

6. Combat/operational "robotic" efforts and concepts are numerous but not open for inclusion in a generalized "robotics program"

7. Due to definitive differences in "robotic" systems as applied to naval aviation operations and support and classical industrial robots, a need exists for the development and maintenance of a robotic (as advanced support technologies) "technology base" for the ultimate design of Navy-applicable systems for the elimination and/or enhancement of the human transfer function

8. The initial robotics studies indicate that a technology base development program should logically be established in NAVAIR (AIR-03), and that this program should encompass both procedures for systematically developing a long-term ASTR technology base as well as systematic response to short-term fleet needs by exploiting state-of-the-art and emergent technologies via concept/technology demonstrator process.

### B. Recommendation

Begin the development and implementation of an Advanced Support Technologies/ Robotics (ASTR) Program within NAVAIR (AIR-03) incorporating both a technology base development and an interdependent and continuing technology demonstrator development process. This program should concentrate on the development of technologies and systems implementing the "Robotic Concept" whereby operational effectiveness, support effectiveness and cost effectiveness are generally increased by using emergent and state-of-the-art technology to enhance or eliminate the human presence or transfer function.

## ADVANCED SUPPORT TECHNOLOGIES/ROBOTICS (ASTR)

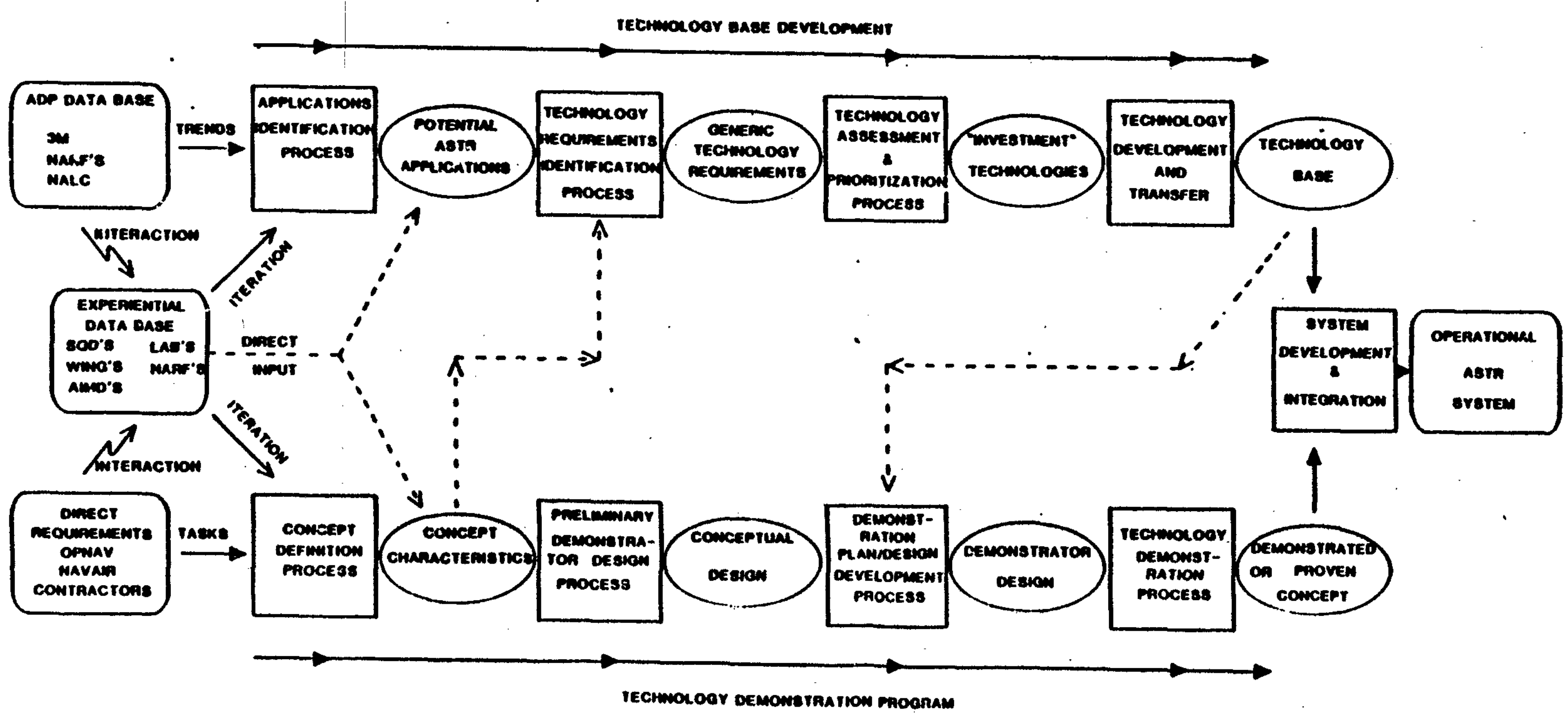


Figure VII-1